

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE 3919

INVESTIGATION OF EFFECTIVENESS OF A
WING EQUIPPED WITH A 50-PERCENT-CHORD SLIDING FLAP, A
30-PERCENT-CHORD SLOTTED FLAP, AND A 30-PERCENT-CHORD
SLAT IN DEFLECTING PROPELLER SLIPSTREAMS
DOWNWARD FOR VERTICAL TAKE-OFF

By Richard E. Kuhn

Langley Aeronautical Laboratory
Langley Field, Va.



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SUMMARY

An investigation of the effectiveness of a wing equipped with a 50-percent-chord sliding flap, a 30-percent-chord slotted flap, and a 30-percent-chord slat in deflecting propeller slipstreams downward for vertical take-off and landing has been conducted in a static-thrust facility at the Langley Aeronautical Laboratory.

The results indicate that with proper settings of the flaps and slat a turning angle of about 70° was obtained both in and out of the ground-effect region, but the ratio of resultant force to thrust varied from about 1.00 with the model in the position nearest the ground to about 0.86 out of the ground-effect region. With the slat installed, the model could be trimmed in pitch with the center of gravity located at 42 percent chord.

INTRODUCTION

The 7- by 10-Foot Tunnels Branch of the Langley Aeronautical Laboratory is conducting investigations of wing-flap configurations to determine their effectiveness in deflecting propeller slipstreams downward for vertical take-off and landing. The characteristics of plain flaps with and without auxiliary vanes are reported in references 1 and 2. The investigation of a slotted-flap configuration is reported in reference 3, ground effect in reference 4, and the effects of a leading-edge slat in reference 5. Reference 6 gives results of a preliminary investigation of a wing equipped with a sliding flap.

The present investigation was undertaken to extend the investigation of the sliding flap by incorporating it in a model using two large-diameter propellers. Also the model was designed to incorporate features evolved from the results of previous investigations where possible.

SYMBOLS

The positive sense of forces, moments, and angles is indicated in figure 1. The pitching moments are presented with reference to the center of gravity shown in figure 2. The symbols used in the present paper are defined as follows:

c	wing chord, ft
c_s	slat chord, ft
\bar{c}	mean aerodynamic chord of wing, ft
D	propeller diameter, ft
F	resultant force, lb
F_X	longitudinal force, lb
h	distance from bottom of fuselage to ground board, ft (fig. 1)
L	lift, lb
M_Y	pitching moment, ft-lb
T	total propeller thrust, lb
α	attitude with respect to ground, deg
δ_f	flap deflection, relative to wing chord, deg
δ_s	slat deflection, relative to wing chord, deg
θ	inclination of resultant force vector from thrust axis, $\tan^{-1} \frac{L}{F_X}$, deg

Subscripts:

30	30-percent-chord flap
50	50-percent-chord flap

APPARATUS AND METHODS

A drawing of the model used in the investigation and its pertinent dimensions are shown in figure 2 and a photograph of the model mounted for testing is shown in figure 3. The geometric characteristics of the wing and propellers are given in the following table:

Wing:

Area (semispan), sq ft	5.50
Span (semispan), ft	3.67
Mean aerodynamic chord, ft	1.51
Airfoil section	NACA 4415
Aspect ratio	4.89
Taper ratio	0.80
Incidence, deg	5

Propellers:

Diameter, ft	2.0
Airfoil section	Clark Y
Solidity (each propeller)	0.07

The ordinates of the slotted flap were derived from the slotted flap 2-h of reference 7 and are presented in table I along with the sketch of the profile of the sliding flap. The cross section of the 30-percent-chord leading-edge slat is also shown in table I. The slat was made of 1/8-inch sheet steel and built up to the desired contour by filling the underside with balsa wood. For these tests the upper surface of the wing was not modified as it would have to be in a practical application in order to retract the slat; however, it is believed that this difference would have only a small effect on the results. The end plate, which was used in most of the tests, was made of 1/16-inch aluminum and is shown in figure 4. It was located 10.3 inches outboard of the center line of the outboard propeller.

The wing was constructed of mahogany supported by a steel spar. The half-fuselage (which served as a support for the horizontal tail used in the investigation of ref. 8) was also constructed of mahogany on a steel backing plate.

The propeller blades, which were constructed of molded Fiberglas and balsa wood, were mounted in aluminum hubs. The propellers were driven by variable-frequency electric motors from a common power supply. During the tests, the propeller rotational speed was approximately 6,000 rpm, which gave a tip Mach number of 0.58. The speed of each propeller was determined by observing a stroboscopic type of indicator, to which was fed the output frequency of a small alternator connected to the motor shaft. For most of the tests, the outboard propeller rotated against the tip vortex (right-hand rotation on right wing) and the inboard propeller rotated in the opposite direction.

The motors were mounted inside aluminum-alloy nacelles by means of strain-gage beams in such a way that the propeller thrust and torque could be measured. The total lift, longitudinal force, and pitching moment of the model were measured on a balance at the root of the wing.

The ground was simulated by a sheet of plywood, as shown in figure 3. The height above the ground h was defined as the distance from the lowest point on the lower side of the half-fuselage to the ground board and was measured perpendicular to the ground board. (See fig. 1.) Most of the tests were run with an attitude of 20° measured from the ground board to the propeller axes.

The investigation was conducted in a static-thrust facility of the Langley Aeronautical Laboratory. All data presented were obtained at zero forward velocity with a thrust of 15 pounds from each propeller. Inasmuch as the tests were conducted under static conditions in a large room, none of the corrections that are normally applicable to wind-tunnel tests were applied.

RESULTS AND DISCUSSION

In planning the configuration for the present investigation, use was made of information obtained in the previous investigations. A large-chord sliding flap (ref. 6) was used in combination with a shorter chord slotted flap in order to reduce the diving moments and at the same time maintain reasonably good turning of the slipstream. Wing incidence of 5° to the thrust line was also used to increase the turning (ref. 3). The thrust line was lowered below the wing chord plane and a leading-edge slat was added to reduce further the diving moments and the adverse effects of the ground (refs. 4 and 5). The span of the wing and slat were increased by adding to the tip so as to capture more fully the slipstream from the outboard propeller (ref. 5).

Effect of End Plate

The effect of end-plate size on the turning effectiveness of the wing is illustrated in figure 5. As can be seen, the installation of an end plate appreciably increased the ratio of resultant force to thrust obtained in the ground-effect region; therefore, for all subsequent tests, an end plate approximately corresponding to end plate C which gave the highest increase in the ratio of resultant force to thrust (fig. 5), was used. The effects of the end plate on the characteristics out of the ground-effect region are shown in figures 6 and 7. With the slat installed, higher turning angles were obtained with the end plate on and, for a given turning angle, the resultant force was not changed. (See

fig. 6(d).) With the slat off (fig. 7(d)), the effects of the end plate were almost negligible.

The difference between the slat-on and slat-off characteristics may be influenced by the spanwise location of the end plate. The end plate was located 10.3 inches (86 percent of the propeller radius) outboard of the outboard-propeller axis. Theoretically the slipstream contracts to 70 percent of the propeller diameter; however, the results of reference 5 indicated that the slat tends to spread the slipstream. The end-plate location was chosen on the basis of the slat-on experience. A more inboard location may possibly produce better results with the slat off.

Effect of Flap and Slat Deflection

The effect of flap deflection on the turning characteristics of the wing with the slat off out of the ground-effect region ($h/d = \infty$) and in the position near the ground ($h/d = 0.08$) are shown in figures 8 and 9, respectively. When out of the ground-effect region and with $\delta_{f,50} = 50^\circ$, a turning angle of about 68° and a ratio of resultant force to thrust of about 0.86 are achieved (fig. 8). In the position near the ground and with the same flap deflection (fig. 9), the turning angle is reduced to 63° , but the ratio of resultant force to thrust is considerably higher. Also, the flap deflections required for maximum turning angle in the ground-effect region are lower than those required for maximum turning angle out of the ground-effect region.

Addition of the leading-edge slat, at a deflection of 10° , increases the turning angle to 74° out of the ground-effect region (fig. 10) and to 69° in the position near the ground (fig. 11). Again, as with the slat-off test (fig. 9), the ratio of resultant force to thrust is considerably increased by the presence of the ground. (Compare figs. 10(d) and 11(d).)

The pitching-moment data are referred to an assumed center-of-gravity location shown in figure 2. With the slat off and with the flaps deflected for maximum turning, the model exhibits diving moments both in and out of the ground-effect region (figs. 8 and 9), even for this rearward center-of-gravity location. Adding the slat, however, effectively counteracts these diving moments at these high turning angles. (See figs. 10 and 11.)

Comparison of figures 8 and 10 indicates that installation of the slat slightly reduced the ratio of resultant force to thrust obtained out of the ground-effect region. The effects of slat deflection on the turning effectiveness are shown in figures 12 and 13. When out of the ground-effect region, decreasing the deflection to zero gave a ratio of resultant force to thrust about equal to that obtained with the slat off

and had little effect on the turning angle. Within the ground-effect region (fig. 13), however, decreasing the slat deflection resulted in a small reduction in turning angle but also gave an increase in the ratio of resultant force to thrust.

The effect of slat deflection on the characteristics at various heights above the ground is presented in figure 14. The ratio of resultant force to thrust is seen to decrease with increasing slat deflection. This effect was also noted in reference 5. At any particular slat setting, the ratio of resultant force to thrust also decreases with increasing height above the ground up to an altitude of about one diameter. Out of the ground-effect region, however, the ratio of resultant force to thrust has increased somewhat from the lowest value reached. This configuration then would have a "ground cushion" (decreasing height, increasing the lift) similar to a helicopter up to a height above the ground of about one diameter. Above this height, there is a reversal (increasing height, decreasing the power required) which would probably not cause any trouble in a vertical take-off but may be troublesome in a vertical landing.

In general, with proper settings of the flaps and slat, a turning angle of about 70° can be obtained both in and out of the ground-effect region, but the ratio of resultant force to thrust varied from about 1.00 with the model in the position nearest the ground ($h/D = 0.08$) to about 0.86 with the model in the position out of the ground-effect region.

Effect of Attitude

All ground-effect tests, both in this investigation and in previous investigations (refs. 4, 5, and 6), have been conducted with an angle of 20° between the propeller thrust axis and the ground board. The effects of reducing this angle are indicated in figure 15. In two positions near the ground ($h/D = 0.08$ and 0.17), decreasing the attitude increases both the turning angle and the ratio of resultant force to thrust. In a third position near the ground ($h/D = 0.83$), however, decreasing the attitude decreases both the turning angle and the ratio of resultant force to thrust. The significance of these variations cannot be assayed only from figure 15 because at an attitude less than that required for hovering (about 20°) a forward component of thrust would be present which would accelerate the airplane to a forward speed. The effects of this forward speed (which ref. 8 indicates can be appreciable) would have to be used in conjunction with the data of figure 15 in assessing the effects of changing attitude.

Effect of Mode of Propeller Rotation

All the data presented herein, with the exception of those presented in figure 16, were obtained with the outboard propeller rotating against the tip vortex (right-hand rotation on a right-hand wing) and the inboard propeller operating in the opposite direction. This arrangement gave the better turning characteristics in reference 2; however, only two of the four possible modes of rotation were investigated in reference 2. The effect of the four modes of rotation on the characteristics are shown in figure 16. The best results are obtained with the outboard propeller rotating against the tip vortex (as was used in all other tests in this report) regardless of the direction of rotation of the other propeller.

Effect of Test-Facility Size

The room in which these tests were made is large (18.5 by 42.5 feet in plan and about 10 feet in height) in relation to the size of the model; however, in order to verify that the results obtained in this facility are indicative of essentially free-air conditions, a few tests were made in a much larger room. The room used was the shop for the Langley 7- by 10-foot tunnels, which is 58 by 98 feet in plan and 16 feet in height. The relative size of the two rooms, as well as the position of the model in the two rooms, is shown in figure 17.

A comparison of the data obtained in the shop of the 7- by 10-foot tunnels and in the room normally used (static-thrust facility) is presented in figure 18. The good agreement obtained indicates that the room normally used is adequate for these tests. However, because of the reduced recirculation effects in the larger room, the model forces were much steadier and easier to read than in the room normally used.

CONCLUSIONS

The investigation of the effectiveness of a wing equipped with a 50-percent-chord sliding flap, a 30-percent-chord slotted flap, and a 30-percent-chord slat in deflecting propeller slipstreams downward for vertical take-off indicates the following conclusions:

1. With proper settings of the flaps and slat, a turning angle of about 70° was obtained both in and out of the ground-effect region, but the ratio of resultant force to thrust varied from about 1.00 with the model in the position nearest the ground to about 0.86 out of the ground-effect region. With the slat installed, the model could be trimmed in pitch with the center of gravity located at 42 percent of the mean aerodynamic chord.

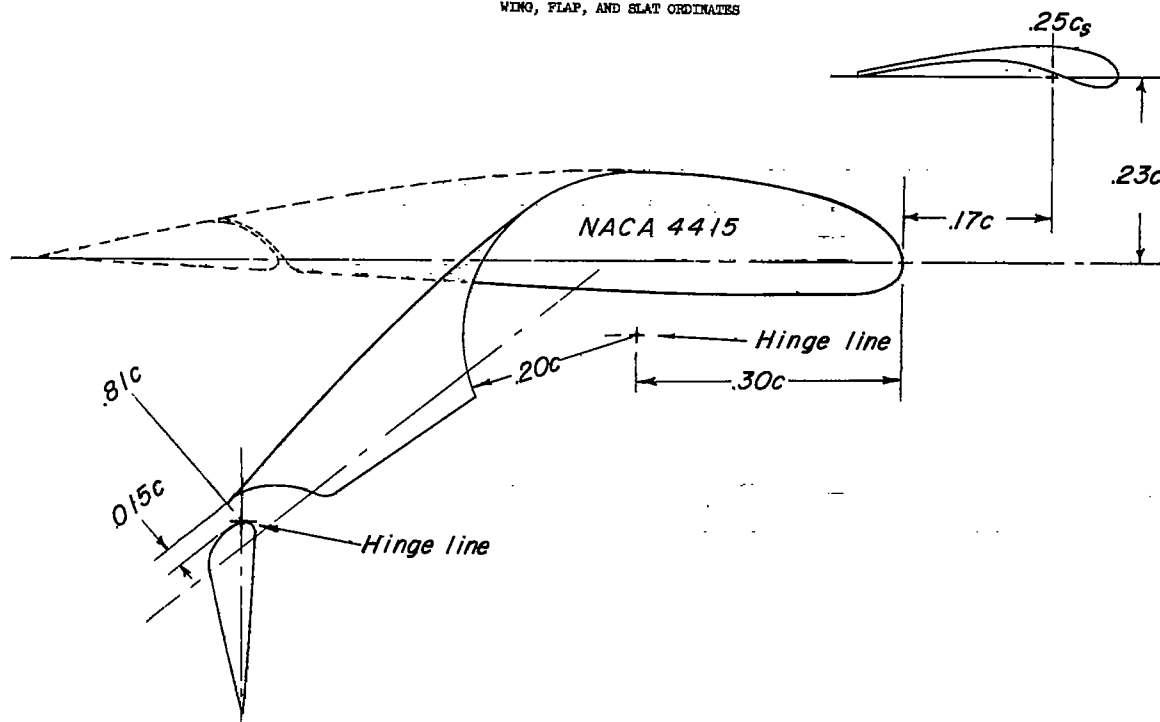
2. The best results were obtained with the outboard propeller rotating against the tip vortex, regardless of the direction of rotation of the inboard propeller.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., October 26, 1956.

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1. Kuhn, Richard E., and Draper, John W.: An Investigation of a Wing-Propeller Configuration Employing Large-Chord Plain Flaps and Large-Diameter Propellers for Low-Speed Flight and Vertical Take-Off. NACA TN 3307, 1954.
2. Draper, John W., and Kuhn, Richard E.: Some Effects of Propeller Operation and Location on Ability of a Wing With Plain Flaps to Deflect Propeller Slipstreams Downward for Vertical Take-Off. NACA TN 3360, 1955.
3. Kuhn, Richard E., and Draper, John W.: Investigation of Effectiveness of Large-Chord Slotted Flaps in Deflecting Propeller Slipstreams Downward for Vertical Take-Off and Low-Speed Flight. NACA TN 3364, 1955.
4. Kuhn, Richard E.: Investigation of the Effects of Ground Proximity and Propeller Position on the Effectiveness of a Wing With Large-Chord Slotted Flaps in Redirecting Propeller Slipstreams Downward for Vertical Take-Off. NACA TN 3629, 1956.
5. Kuhn, Richard E.: Investigation at Zero Forward Speed of a Leading-Edge Slat as a Longitudinal Control Device for Vertically Rising Airplanes That Utilize the Redirected-Slipstream Principle. NACA TN 3692, 1956.
6. Kuhn, Richard E., and Spreemann, Kenneth P.: Preliminary Investigation of the Effectiveness of a Sliding Flap in Deflecting a Propeller Slipstream Downward for Vertical Take-Off. NACA TN 3693, 1956.
7. Wenzinger, Carl J., and Harris, Thomas A.: Wind-Tunnel Investigation of an N.A.C.A. 23012 Airfoil With Various Arrangements of Slotted Flaps. NACA Rep. 664, 1939.
8. Kuhn, Richard E., and Hayes, William C., Jr.: Wind-Tunnel Investigation of Effect of Propeller Slipstreams on Aerodynamic Characteristics of a Wing Equipped With a 50-Percent-Chord Sliding Flap and a 30-Percent-Chord Slotted Flap. NACA TN 3918, 1957.

TABLE I
WING, FLAP, AND SLAT ORDINATES



Slotted-flap ordinates

Station, fraction of wing chord	Ordinate, fraction of wing chord		
	Slot	Flap nose	
		Upper	Lower
0.65	-0.0180	-----	-----
.66	-.0175	-----	-----
.67	-.0169	-----	-----
.68	-.0145	-----	-----
.69	-.0080	-----	-----
.70	.0160	0.0075	0.0075
.705	-----	.0210	-.0020
.71	.0280	.0260	-.0050
.72	.0375	.0350	-.0080
.73	.0430	.0415	-.0115
.74	.0470	.0465	-.0125
.75	.0500	.0490	-.0125
.76	.0520	.0510	-----
.77	.0530	.0520	-----
.78	.0535	.0525	-----
.79	.0535	.0525	-----
.80	.0530	.0520	-----
.81	.0531	.0515	-----
.82	-----	.0505	-----
.83	-----	.0485	-----

Slat ordinates

Station, fraction of slat chord	Ordinates, fraction of slat chord	
	Upper	Lower
0	0	0
.025	.060	-.023
.050	.083	-.027
.075	.097	-.025
.100	.105	-.023
.150	.115	-.007
.200	.120	.012
.250	.122	.030
.300	.122	.046
.400	.116	.070
.500	.105	.080
.600	.090	.071
.700	.073	.056
.800	.055	.039
.900	.035	.020
1.000	.013	0

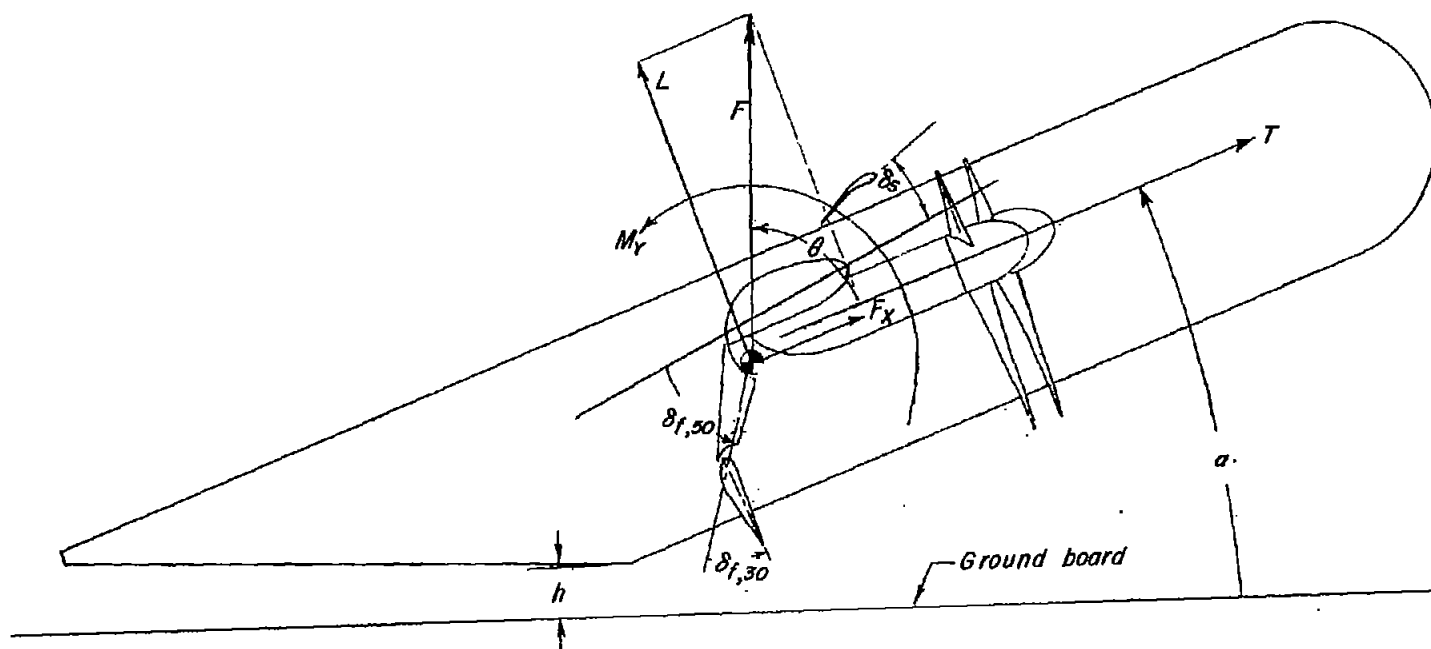
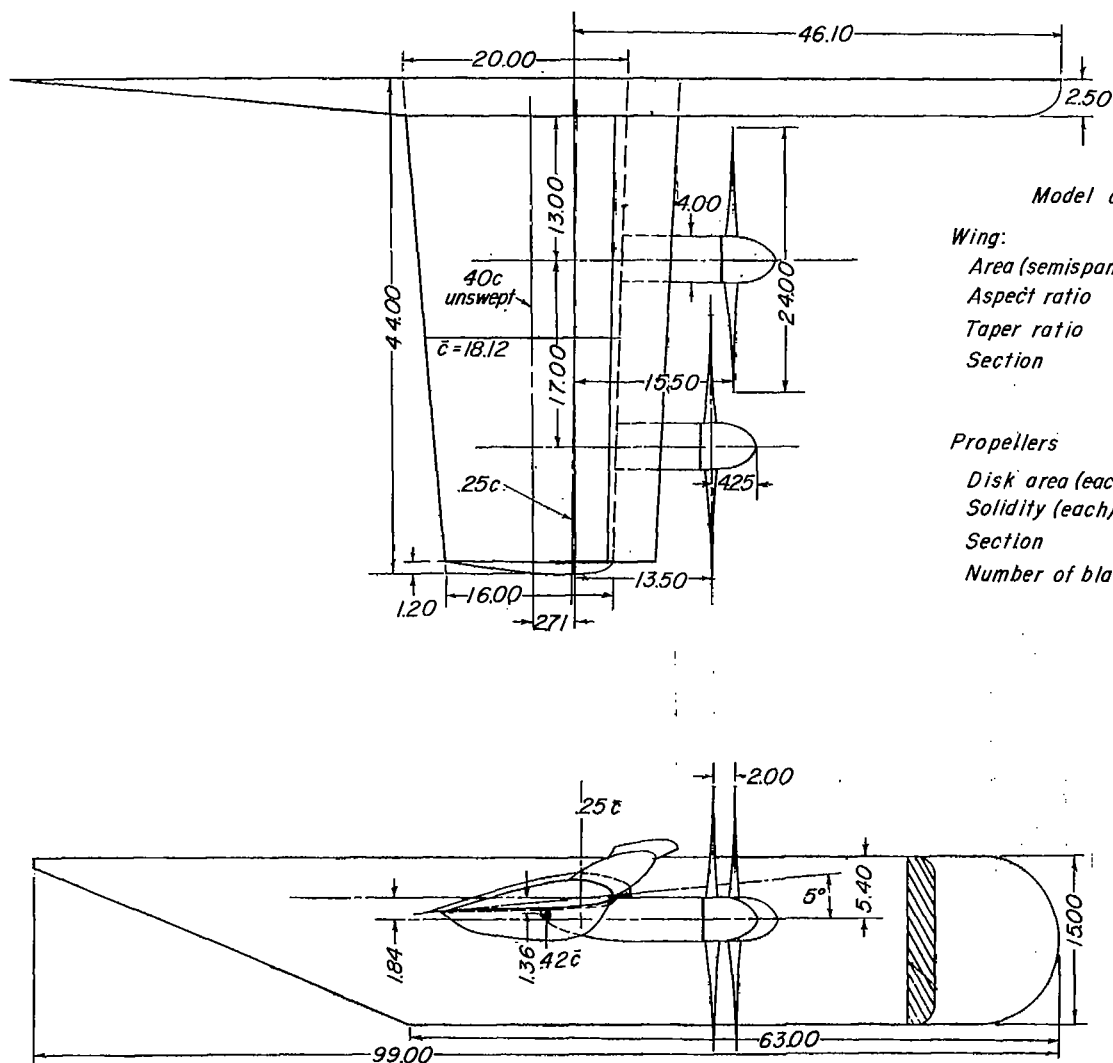


Figure 1.- Conventions used to define positive sense of forces, moments, and angles.



Model characteristics

Wing:

Area (semispan), sq ft	5.50
Aspect ratio	4.89
Taper ratio	0.80
Section	NACA 4415

Propellers

Disk area (each), sq ft	3.14
Solidity (each)	0.07
Section	Clark y
Number of blades	3

Figure 2.- Drawing of model. All dimensions in inches.



L-94231.1
Figure 3.- Photograph of the model installed on the static-thrust stand for testing.

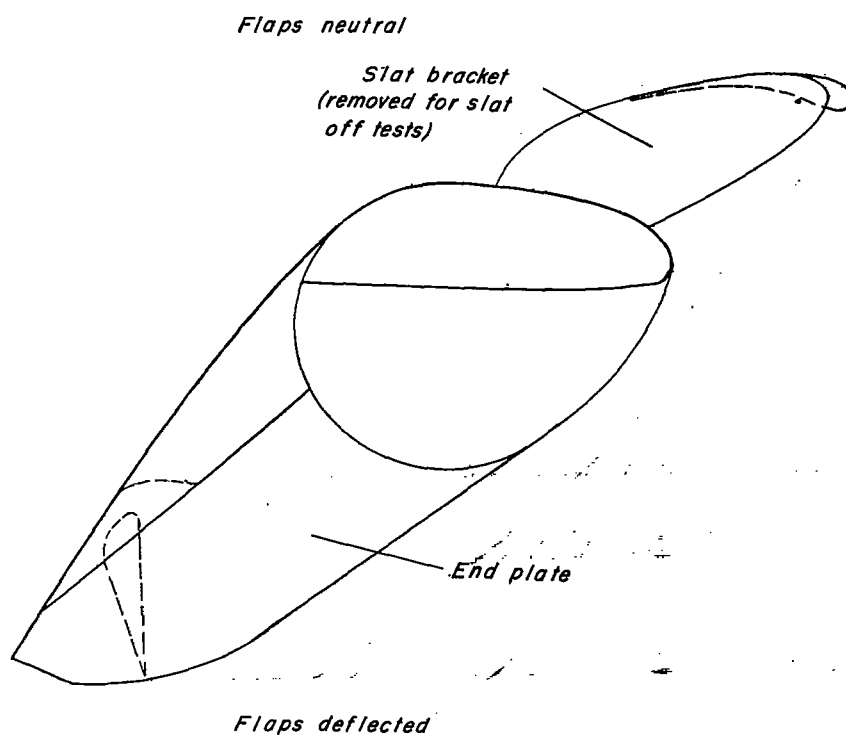
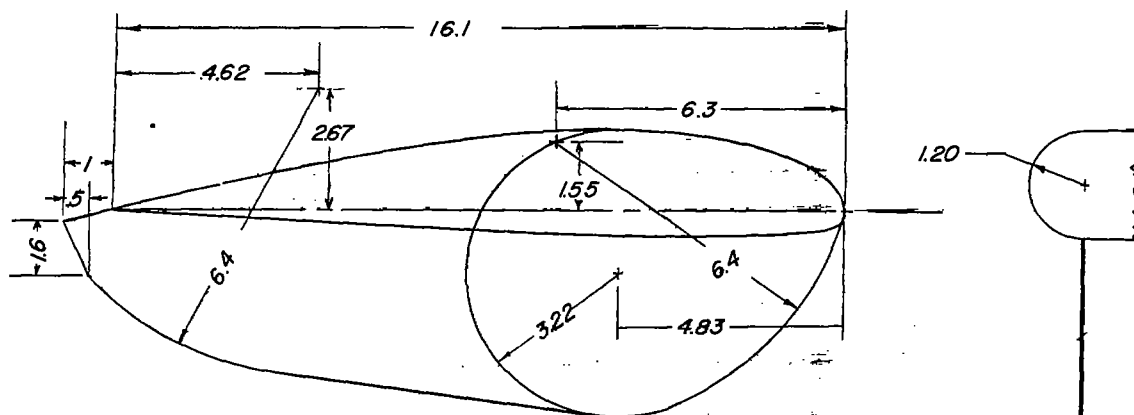


Figure 4.- Details of the end plate.

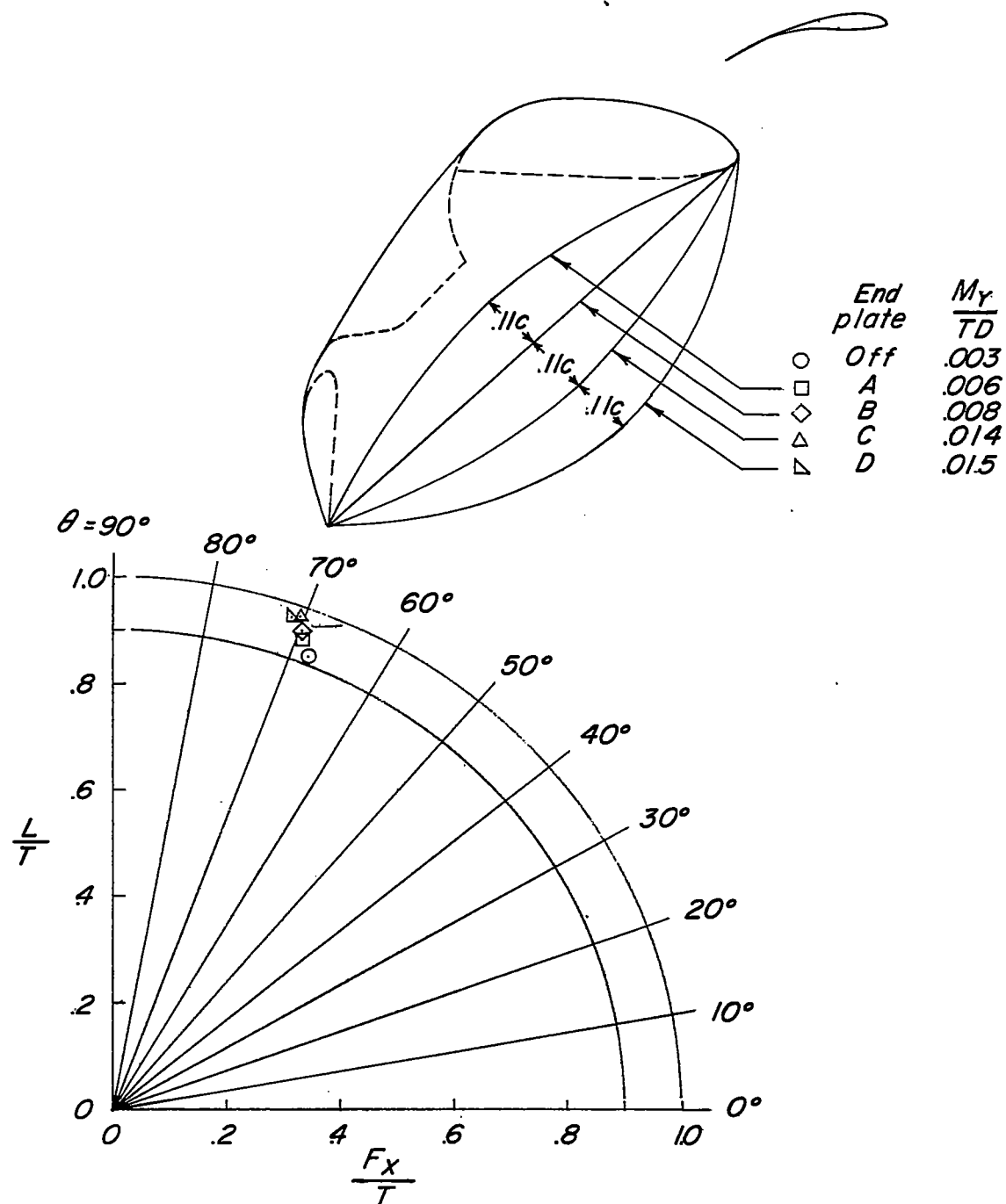
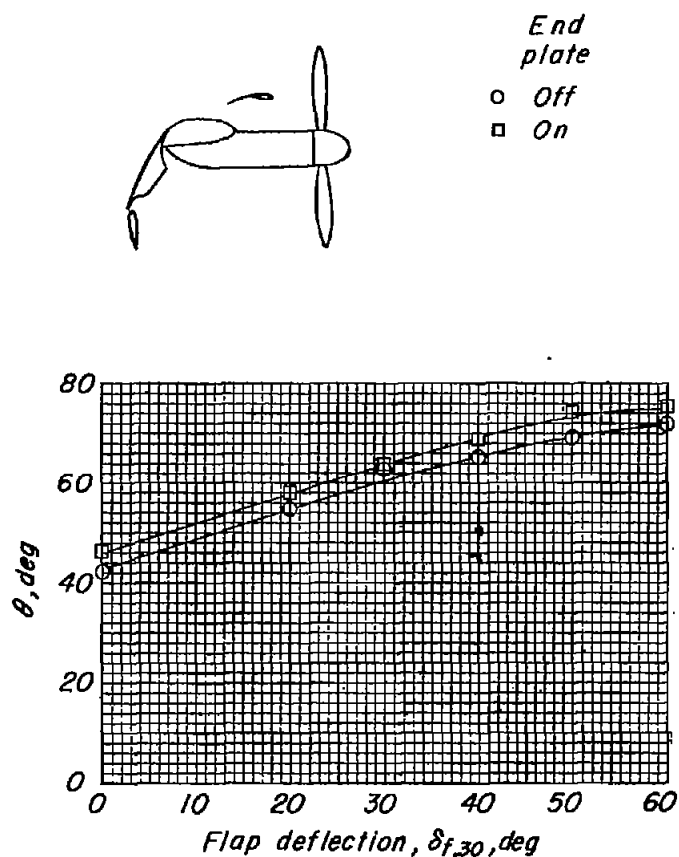
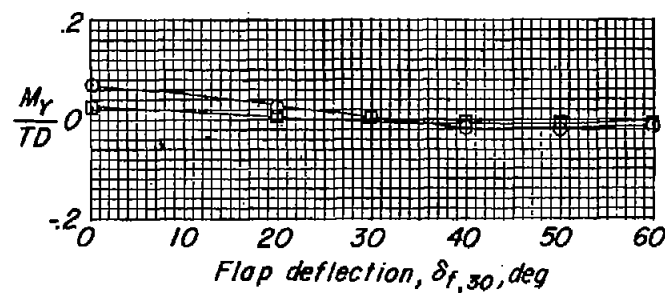


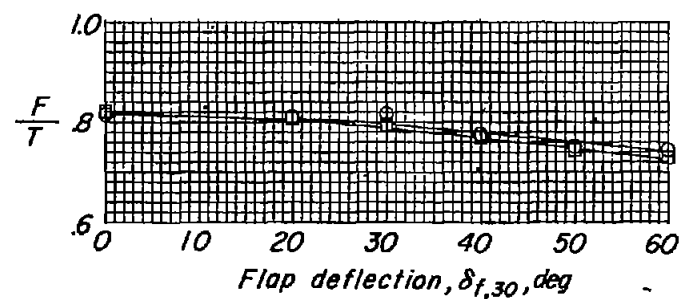
Figure 5.- Effect of end-plate size. Slat on; $\delta_s = 20^\circ$; $\delta_{f,50} = 50^\circ$; $\delta_{f,30} = 40^\circ$; $h/D = 0.04$.



(a) Turning angle.

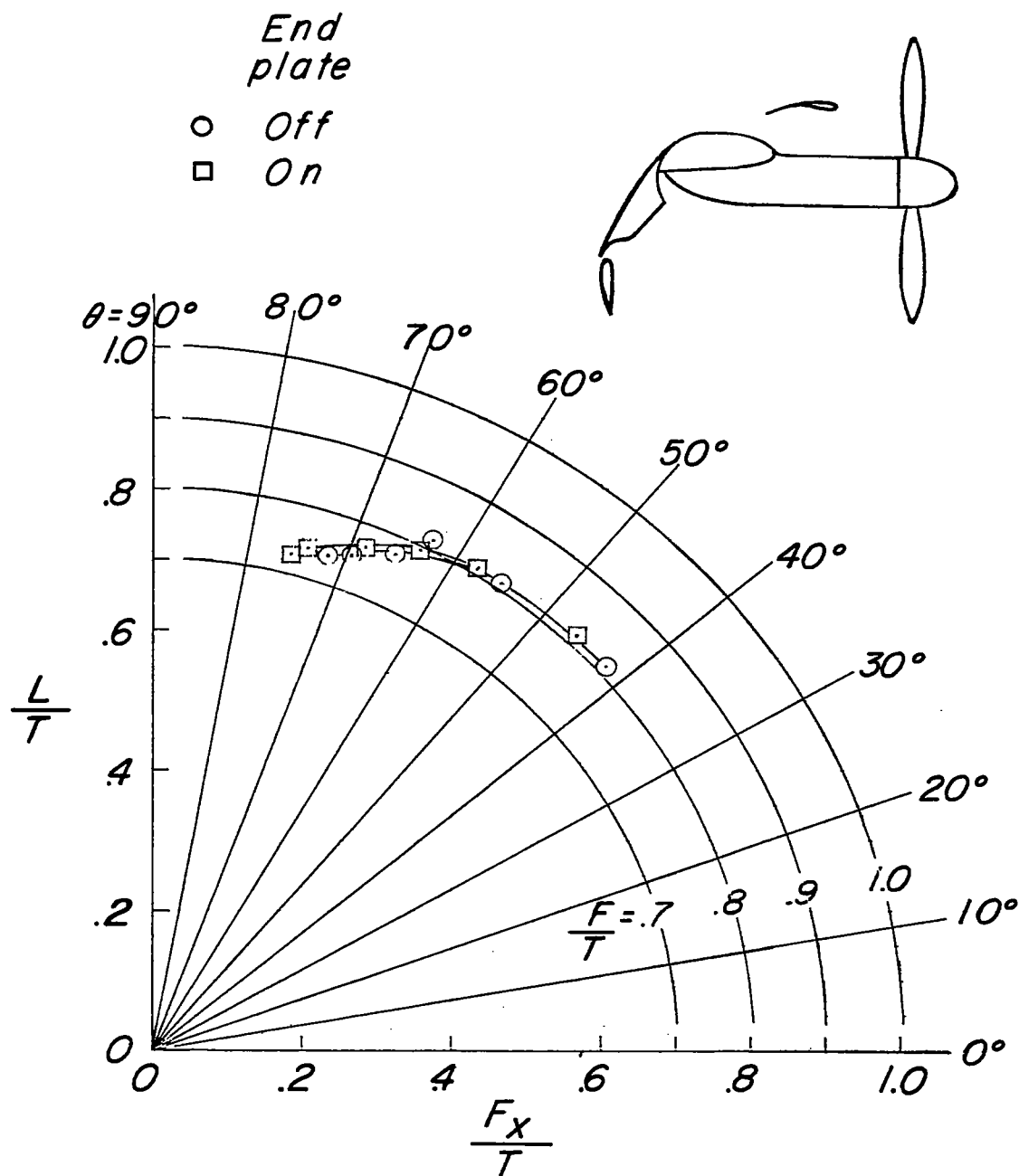


(b) Pitching moment.



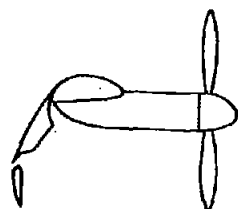
(c) Ratio of resultant force to thrust.

Figure 6.- Effect of end plate. Slat on; $\delta_S = 20^\circ$; $\delta_{f,50} = 50^\circ$; $h/D = \infty$.

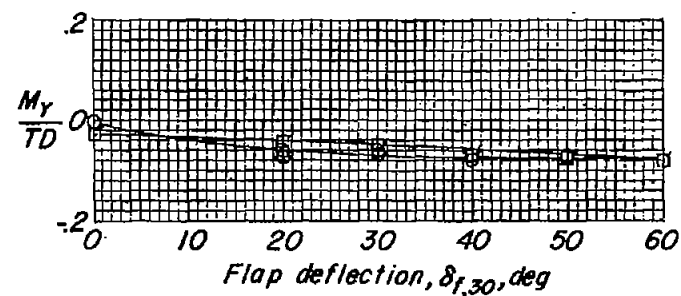


(d) Summary of turning effectiveness.

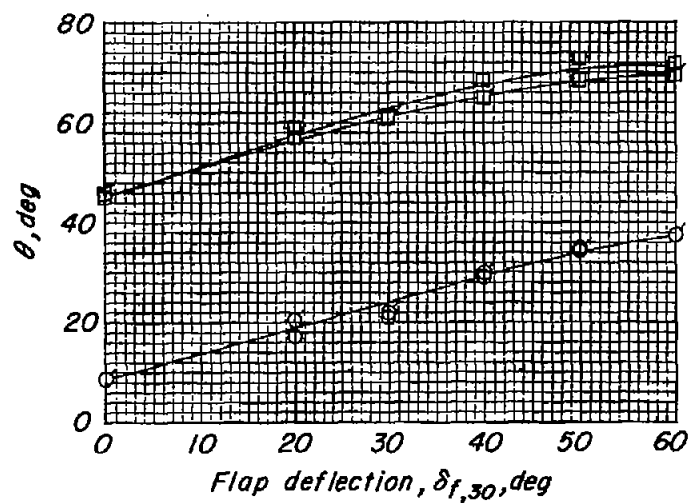
Figure 6.- Concluded.



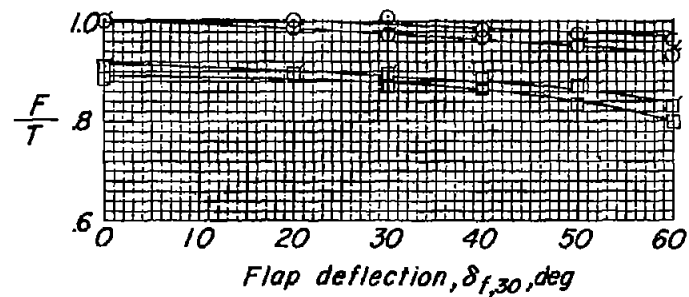
	End plate	$\delta_{f,50}$, deg
○	Off	0
◊	On	0
□	Off	50
◻	On	50



(b) Pitching moment.

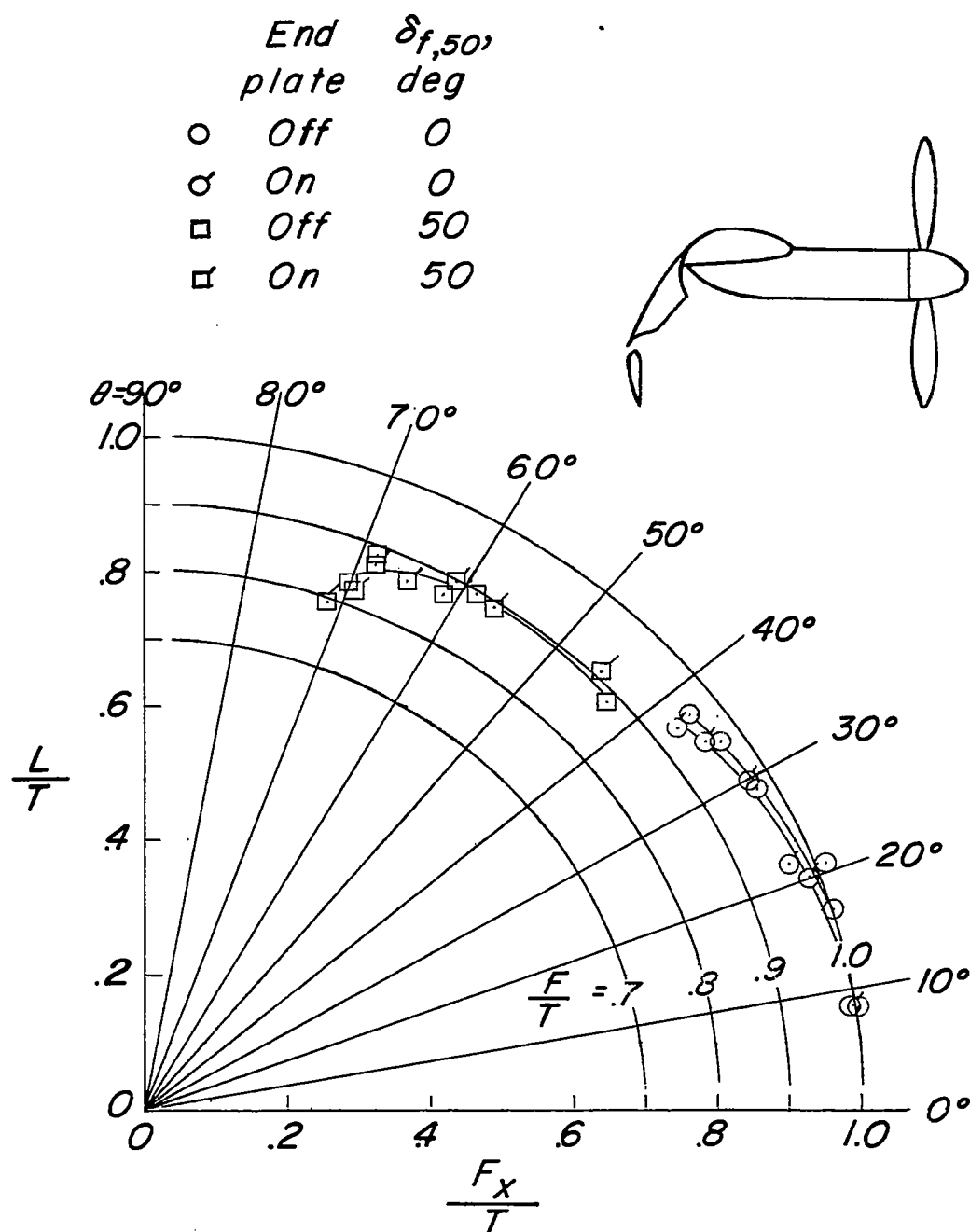


(a) Turning angle.



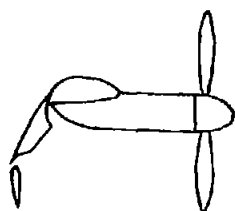
(c) Ratio of resultant force to thrust.

Figure 7.- Effect of end plate. Slat off; $h/D = \infty$.

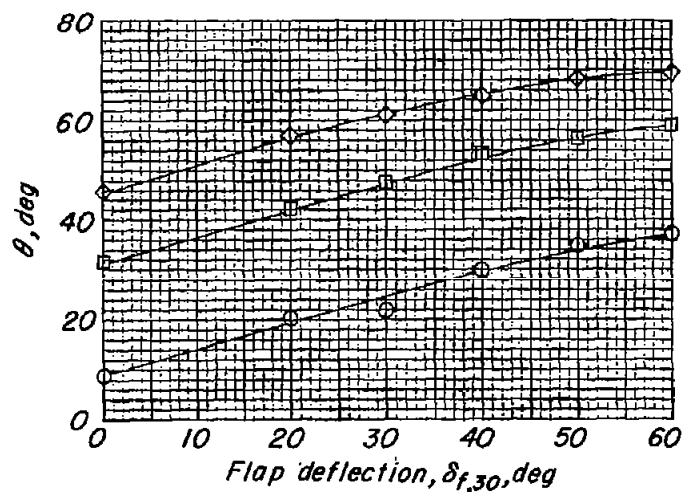


(d) Summary of turning effectiveness.

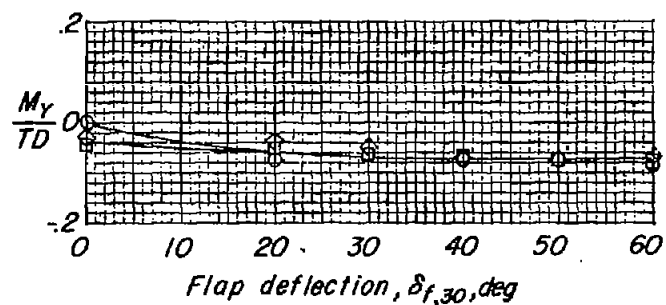
Figure 7.- Concluded.



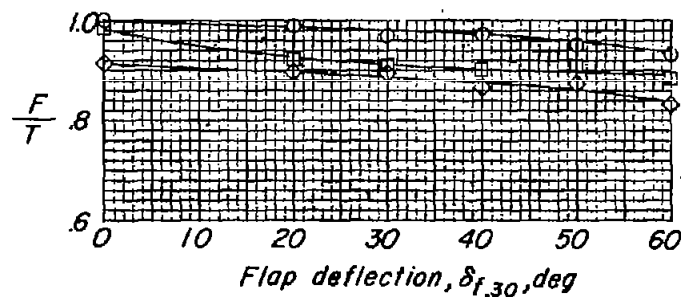
$\delta_{f,50}$
deg
○ 0
□ 30
◇ 50



(a) Turning angle.

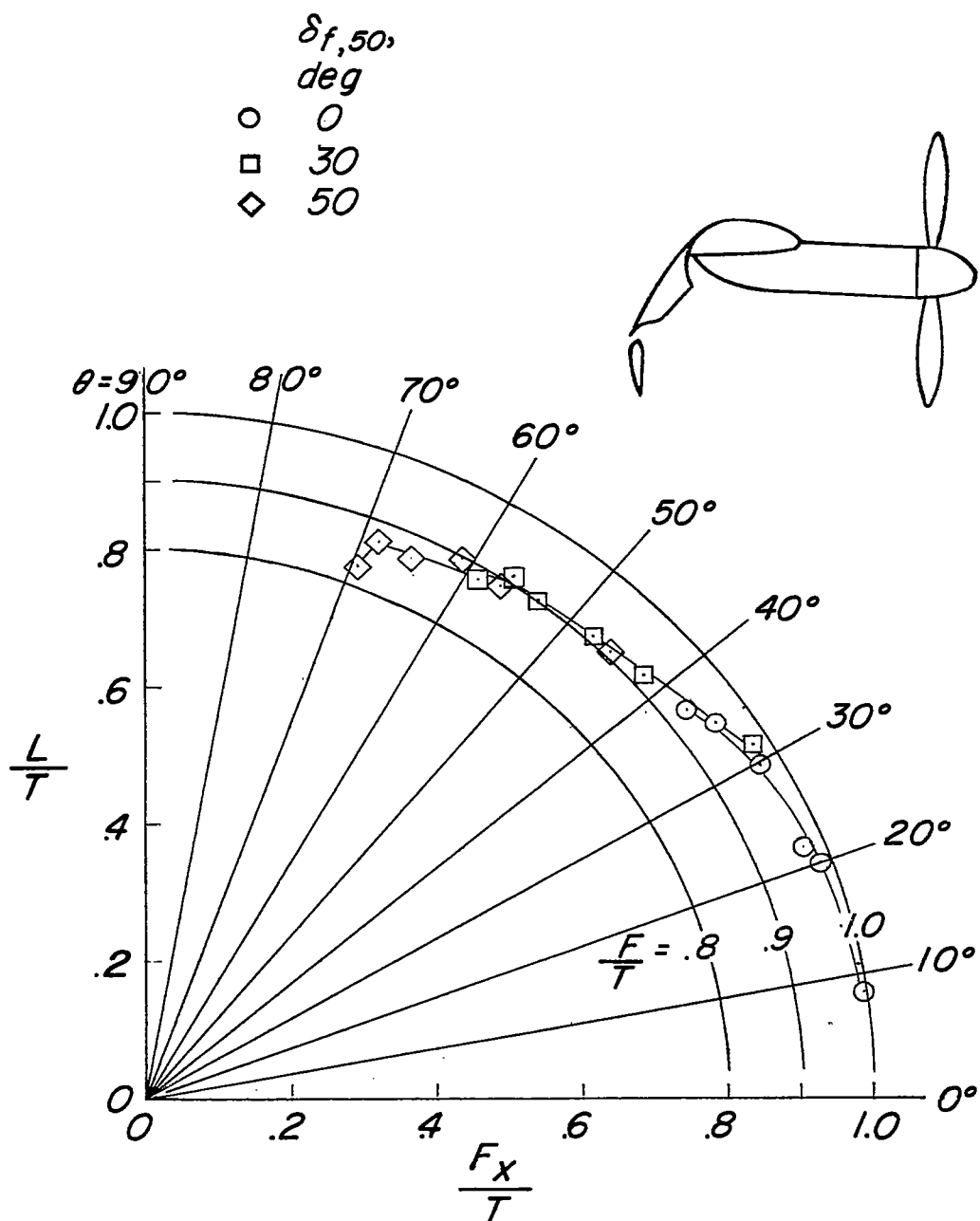


(b) Pitching moment.



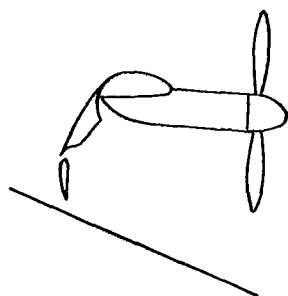
(c) Ratio of resultant force to thrust.

Figure 8.- Effect of flap deflection. Slat off; end plate on; $h/D = \infty$.



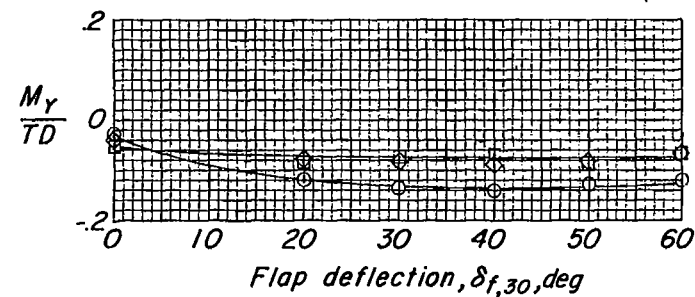
(d) Summary of turning effectiveness.

Figure 8.- Concluded.

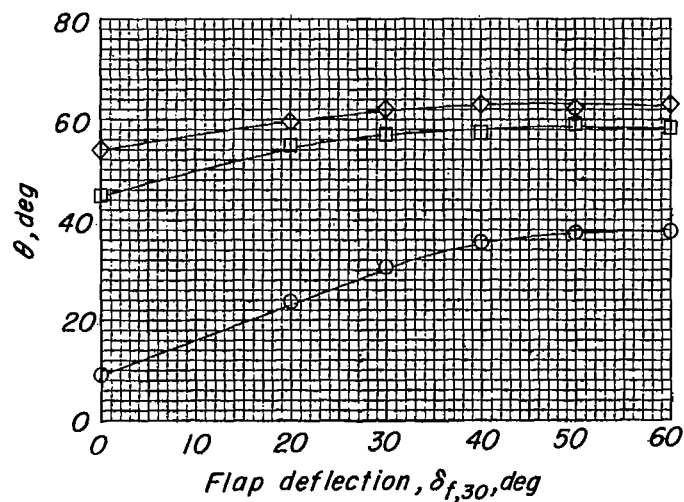


$\delta_{f,50}$,
deg

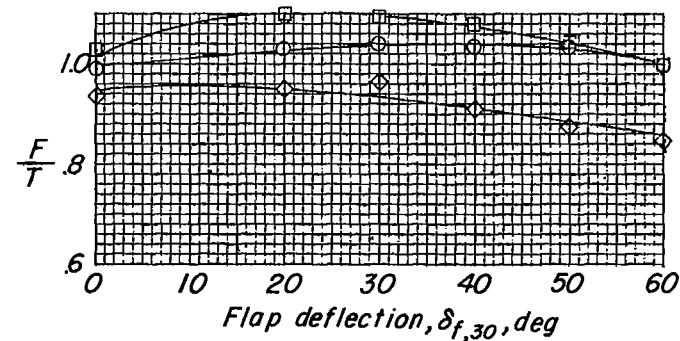
○ 0
□ 30
◇ 50



(b) Pitching moment.

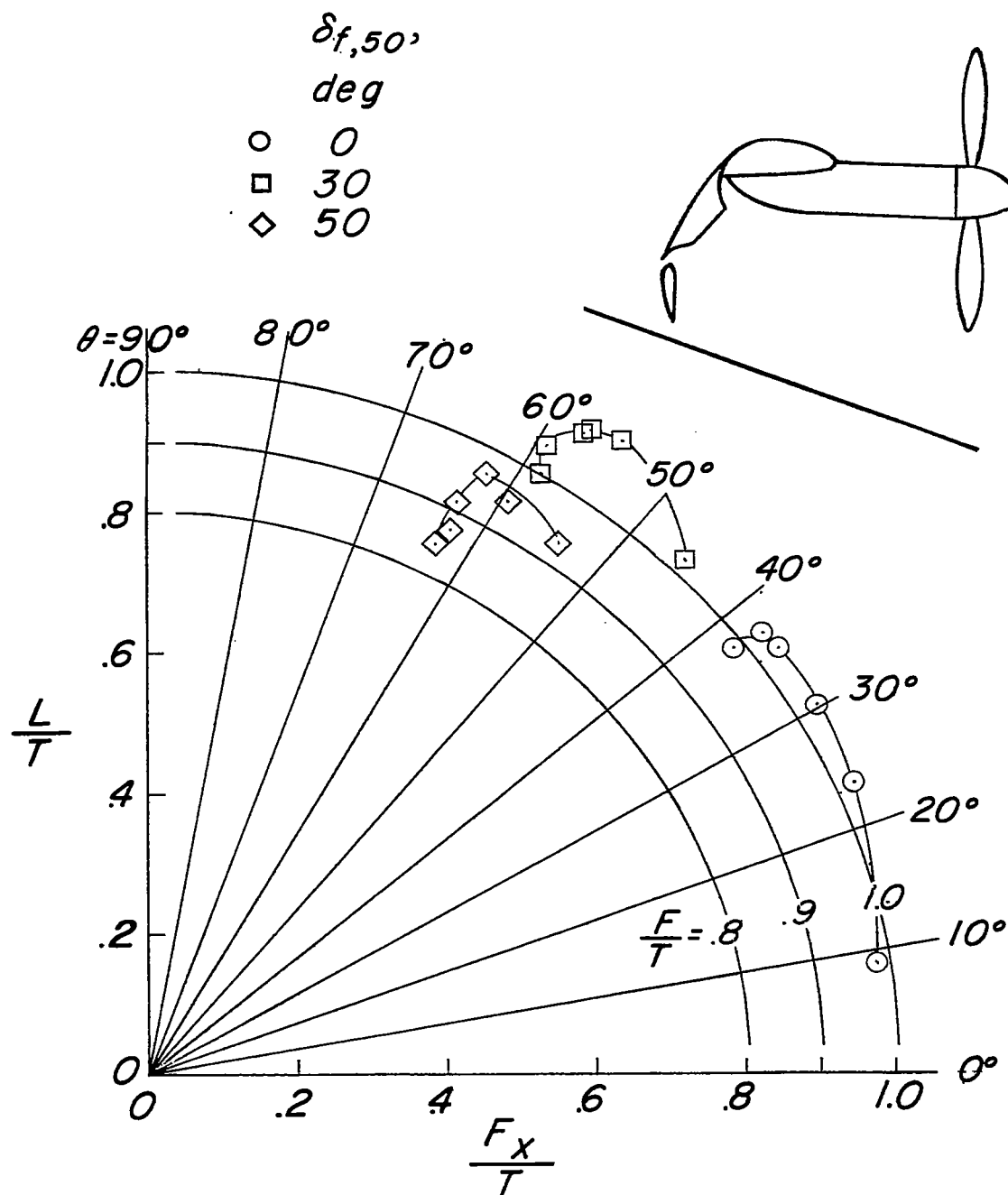


(a) Turning angle.



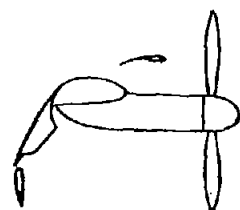
(c) Ratio of resultant force to thrust.

Figure 9.- Effect of flap deflection. Slat off; end plate on; $h/D = 0.08$.

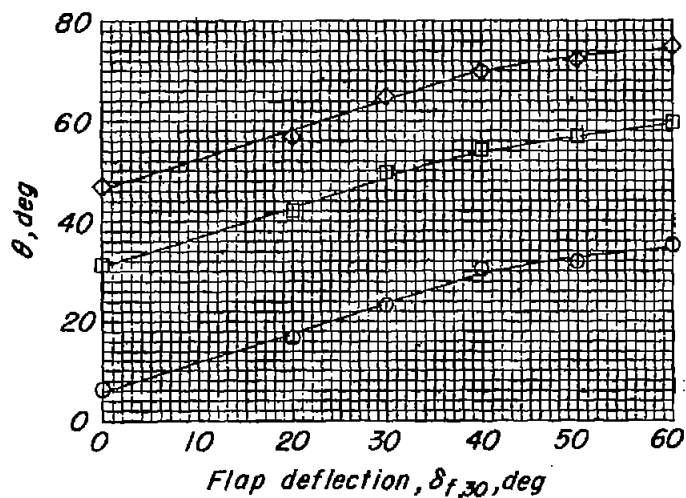


(d) Summary of turning effectiveness.

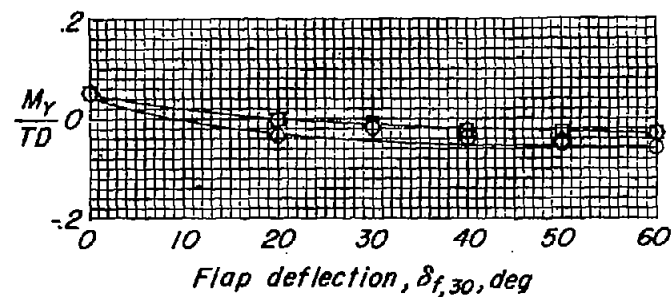
Figure 9.- Concluded.



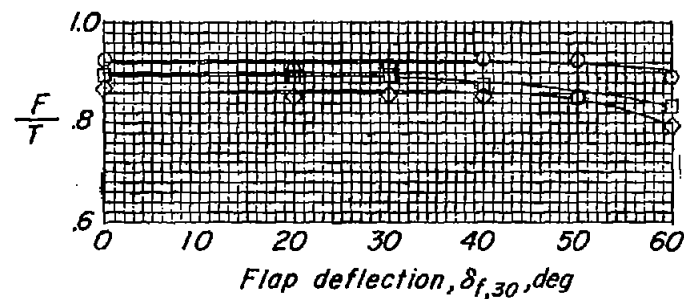
$\delta_{f,50}$,
deg
○ 0
□ 30
◇ 50



(a) Turning angle.

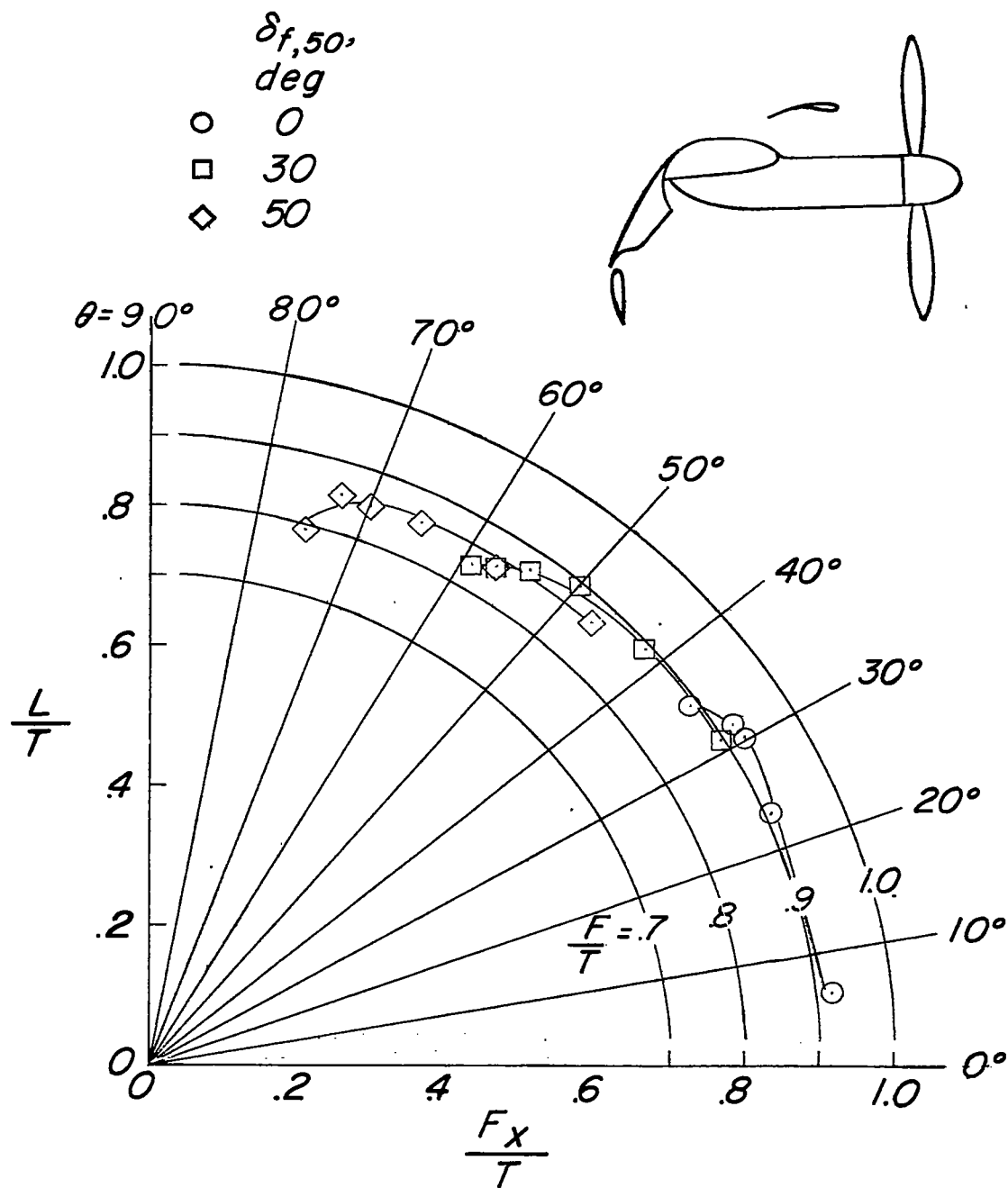


(b) Pitching moment.



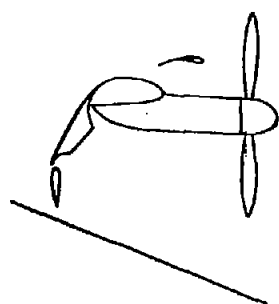
(c) Ratio of resultant force to thrust.

Figure 10.- Effect of flap deflection. Slat on; $\delta_s = 10^\circ$; end plate on; $h/D = \infty$.



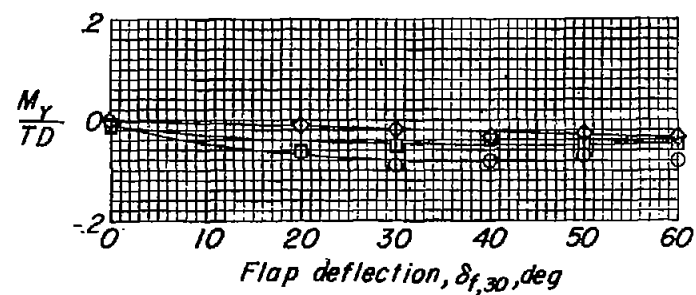
(d) Summary of turning effectiveness.

Figure 10.- Concluded.

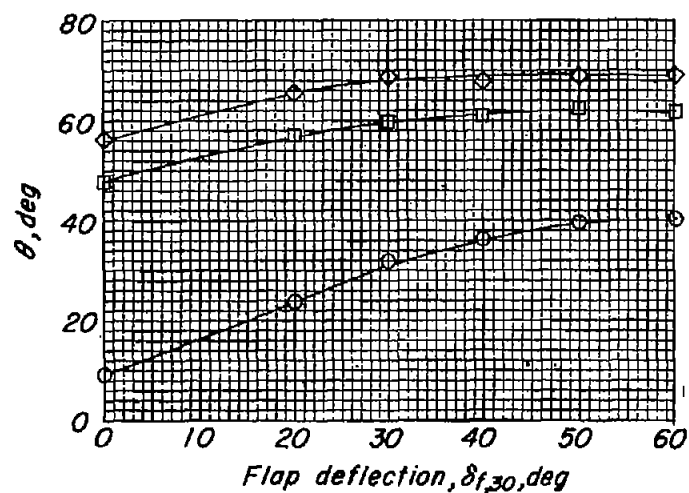


$\delta_{f,50}$,
deg

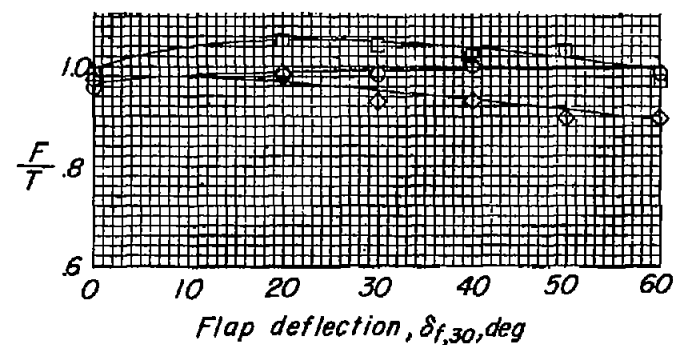
○ 0
□ 30
◇ 50



(b) Pitching moment.

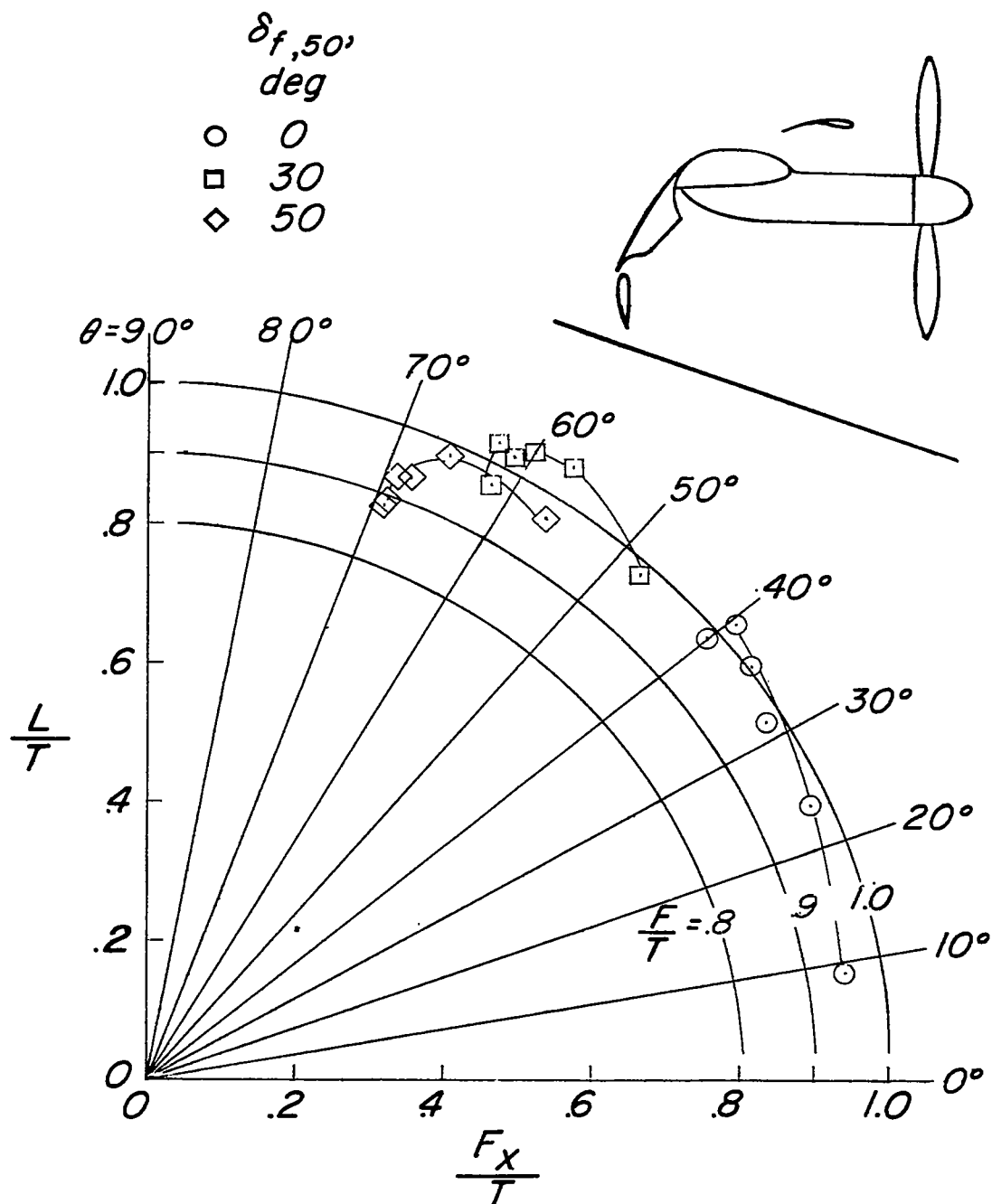


(a) Turning angle.



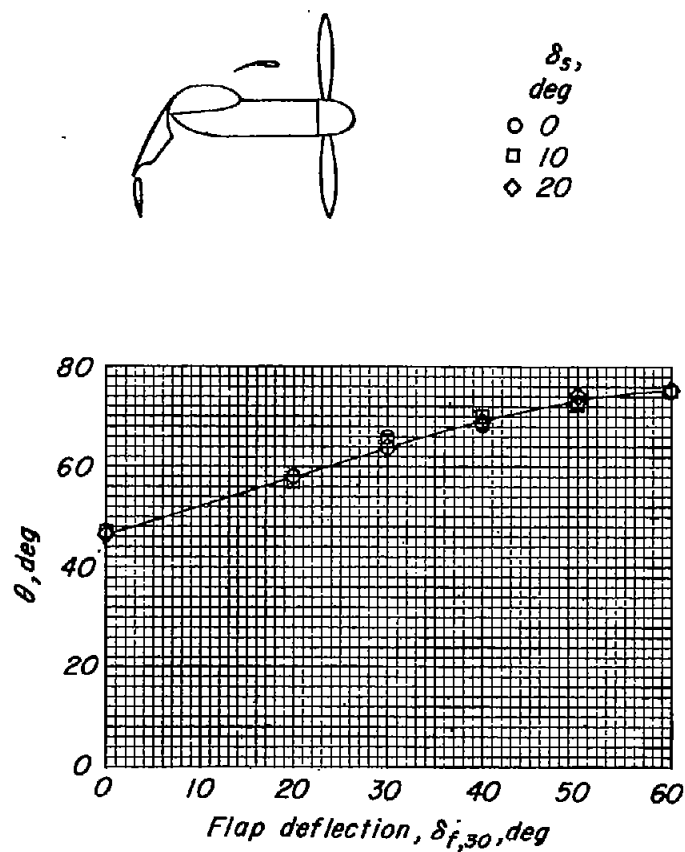
(c) Ratio of resultant force to thrust.

Figure 11.- Effect of flap deflection. Slat on; $\delta_s = 10^\circ$; end plate on; $h/D = 0.08$.

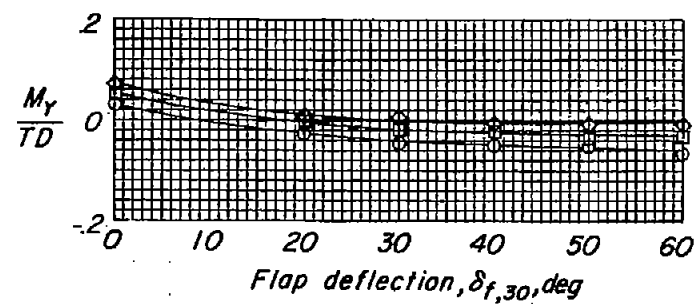


(d) Summary of turning effectiveness.

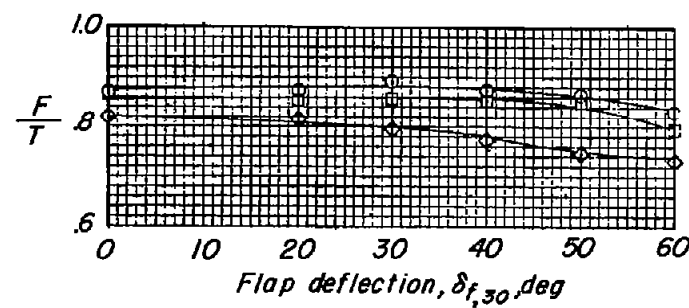
Figure 11.- Concluded.



(a) Turning angle.

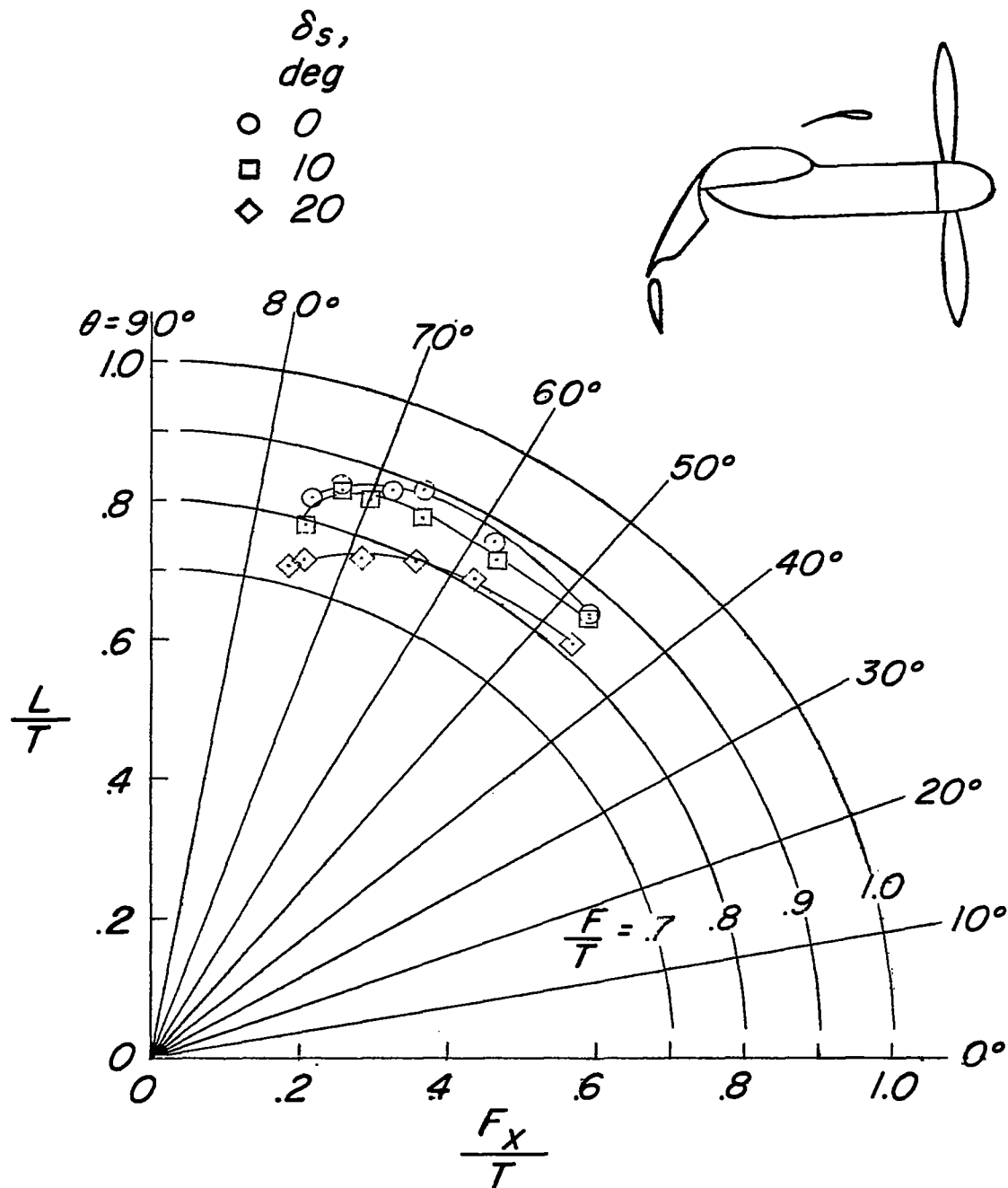


(b) Pitching moment.



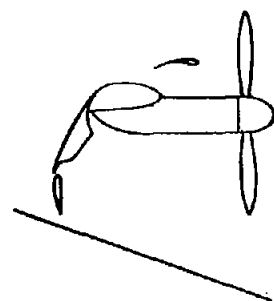
(c) Ratio of resultant force to thrust.

Figure 12.- Effect of slat deflection. End plate on; $\delta_{f,50} = 50^\circ$; $h/D = \infty$.

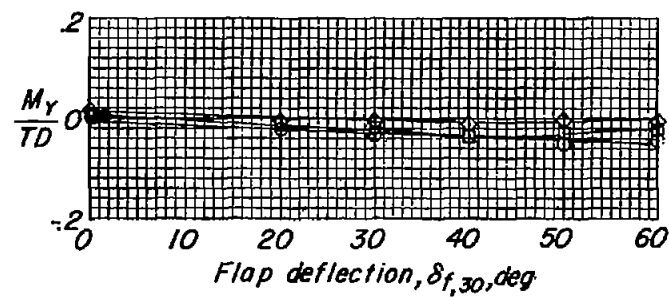


(d) Summary of turning effectiveness.

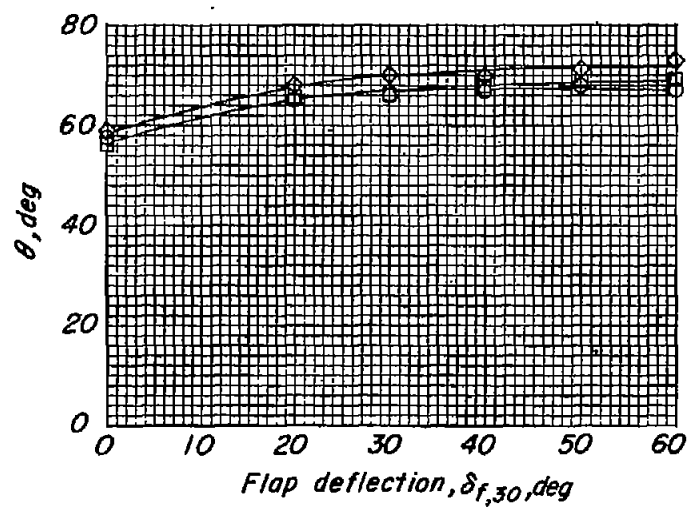
Figure 12.- Concluded.



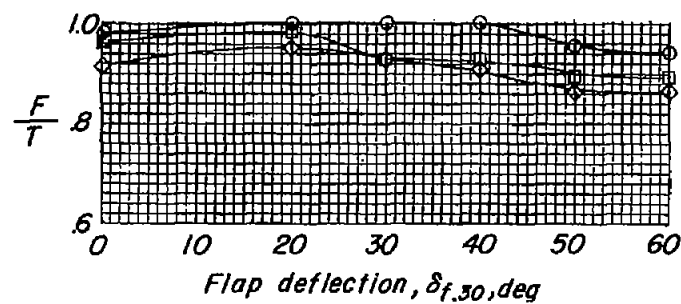
δ_s ,
deg
○ 0
□ 10
◇ 20



(b) Pitching moment.

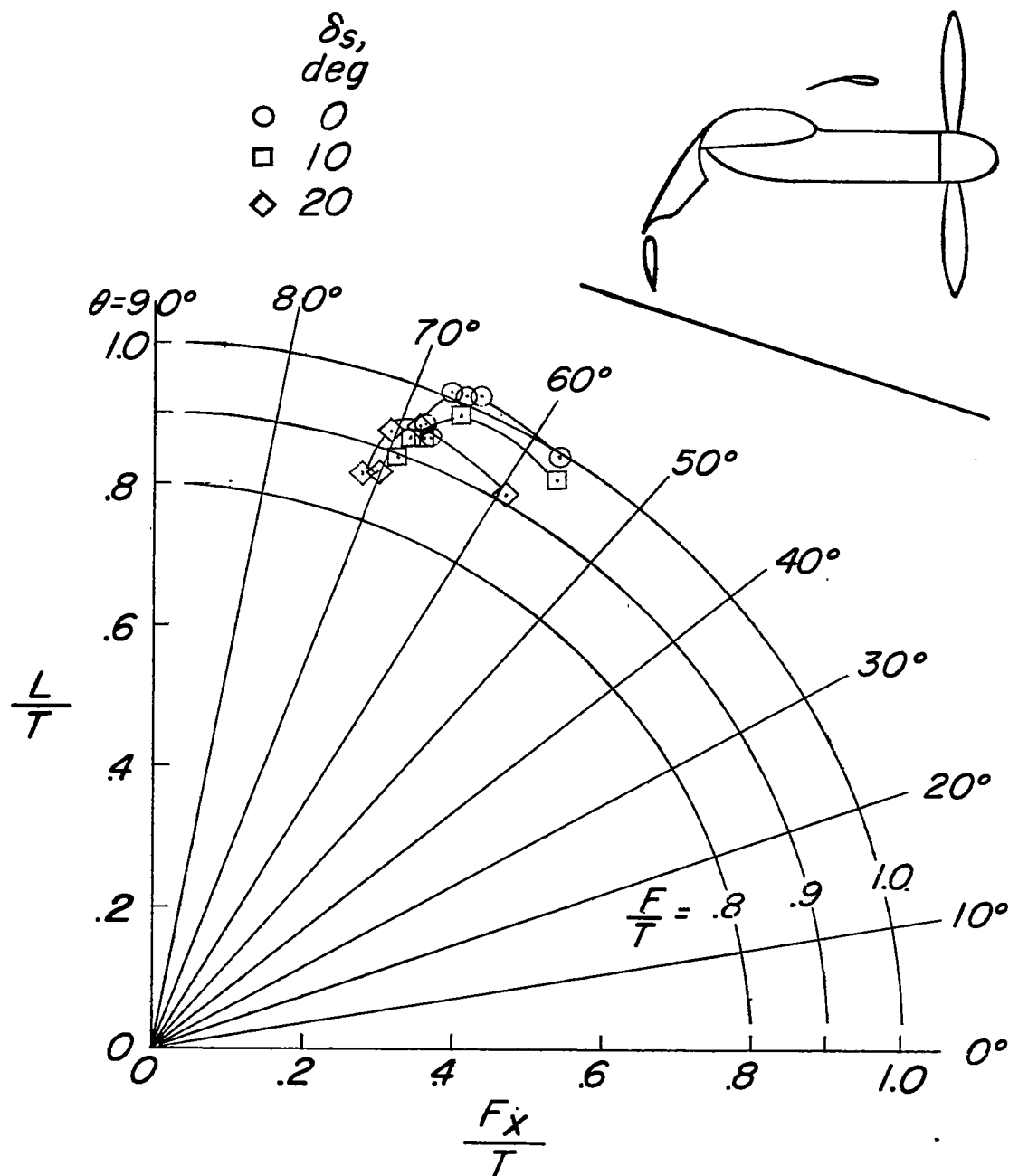


(a) Turning angle.



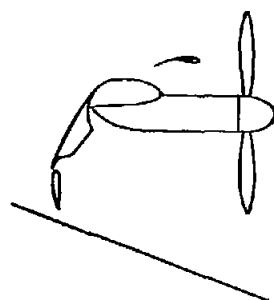
(c) Ratio of resultant force to thrust.

Figure 13.- Effect of slat deflection. End plate on; $\delta_{f,50} = 50^\circ$; $h/D = 0.08$.



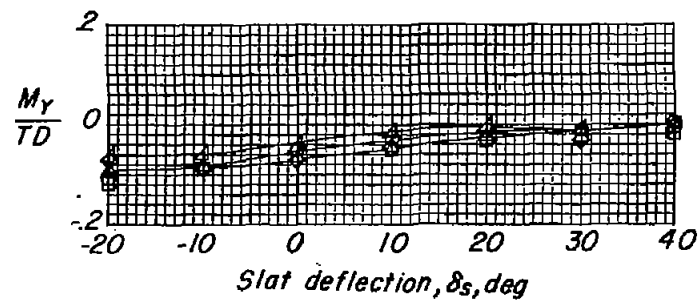
(d) Summary of turning effectiveness.

Figure 13.- Concluded.

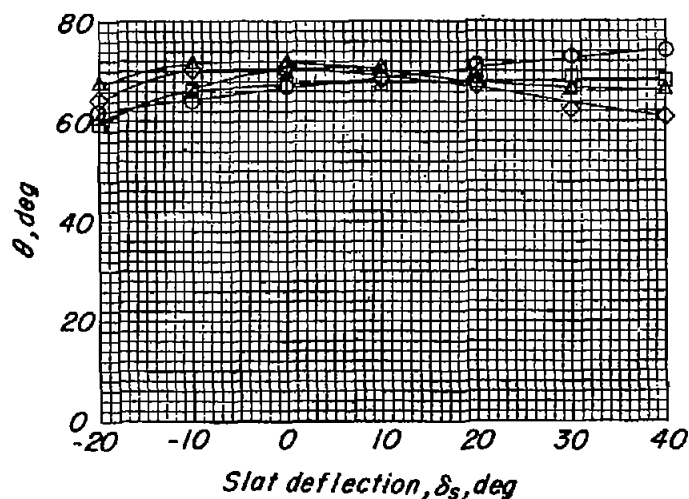


h/D

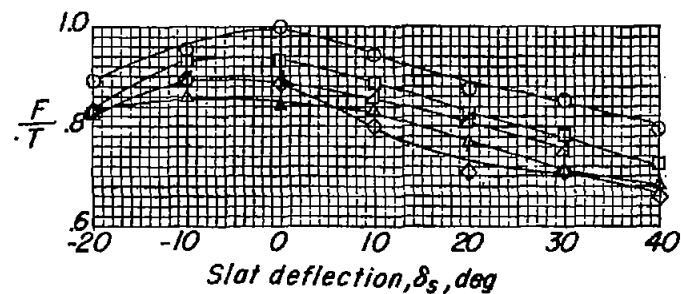
- 0.08
- .17
- ◇ .83
- △ 1.38
- Δ ∞



(b) Pitching moment.

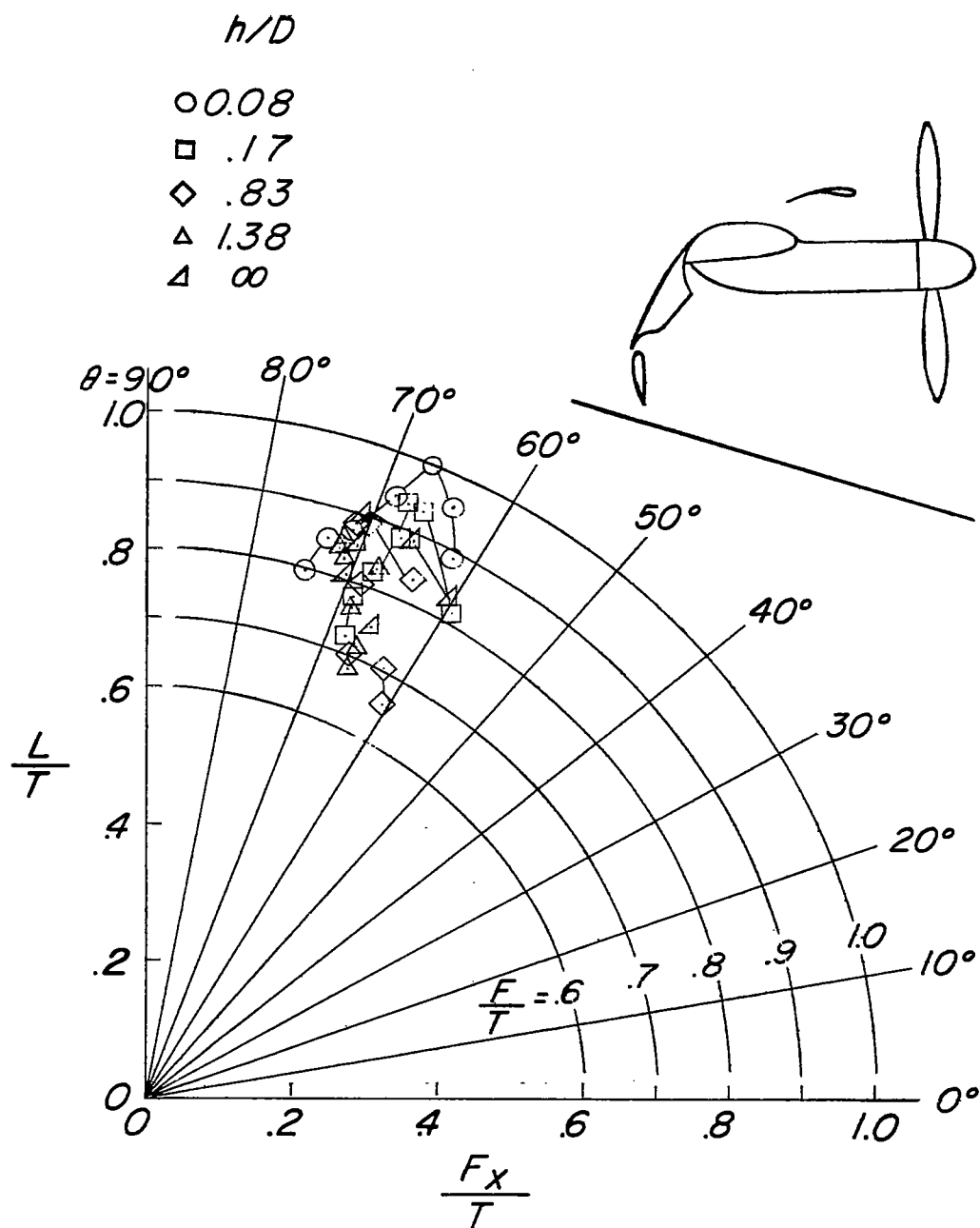


(a) Turning angle.



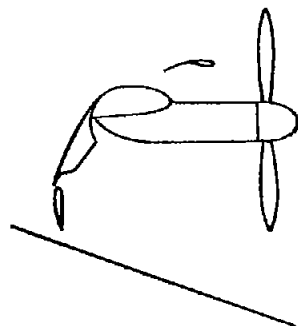
(c) Ratio of resultant force to thrust.

Figure 14.- Effect of height above the ground. Slat on; end plate on; $\delta_{f,50} = 50^\circ$; $\delta_{f,30} = 40^\circ$.

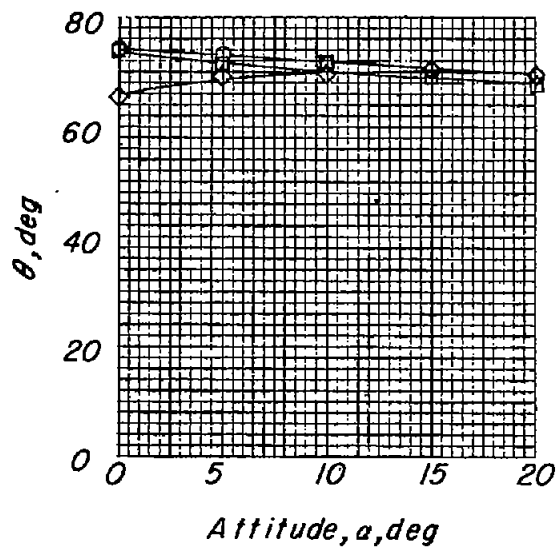


(d) Summary of turning effectiveness.

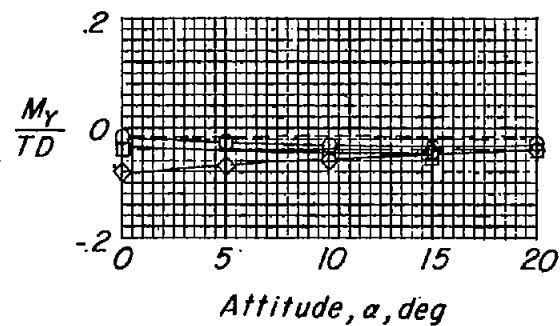
Figure 14.- Concluded.



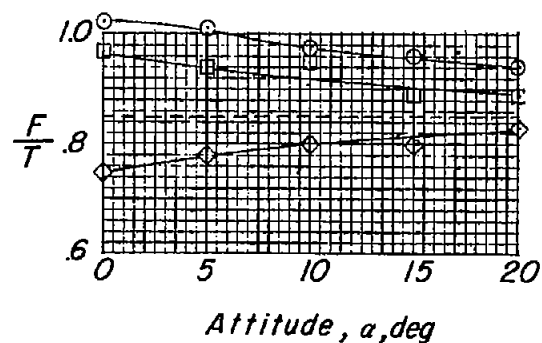
h/D
 \circ .08
 \square .17
 \diamond .83
 --- ∞



(a) Turning angle.

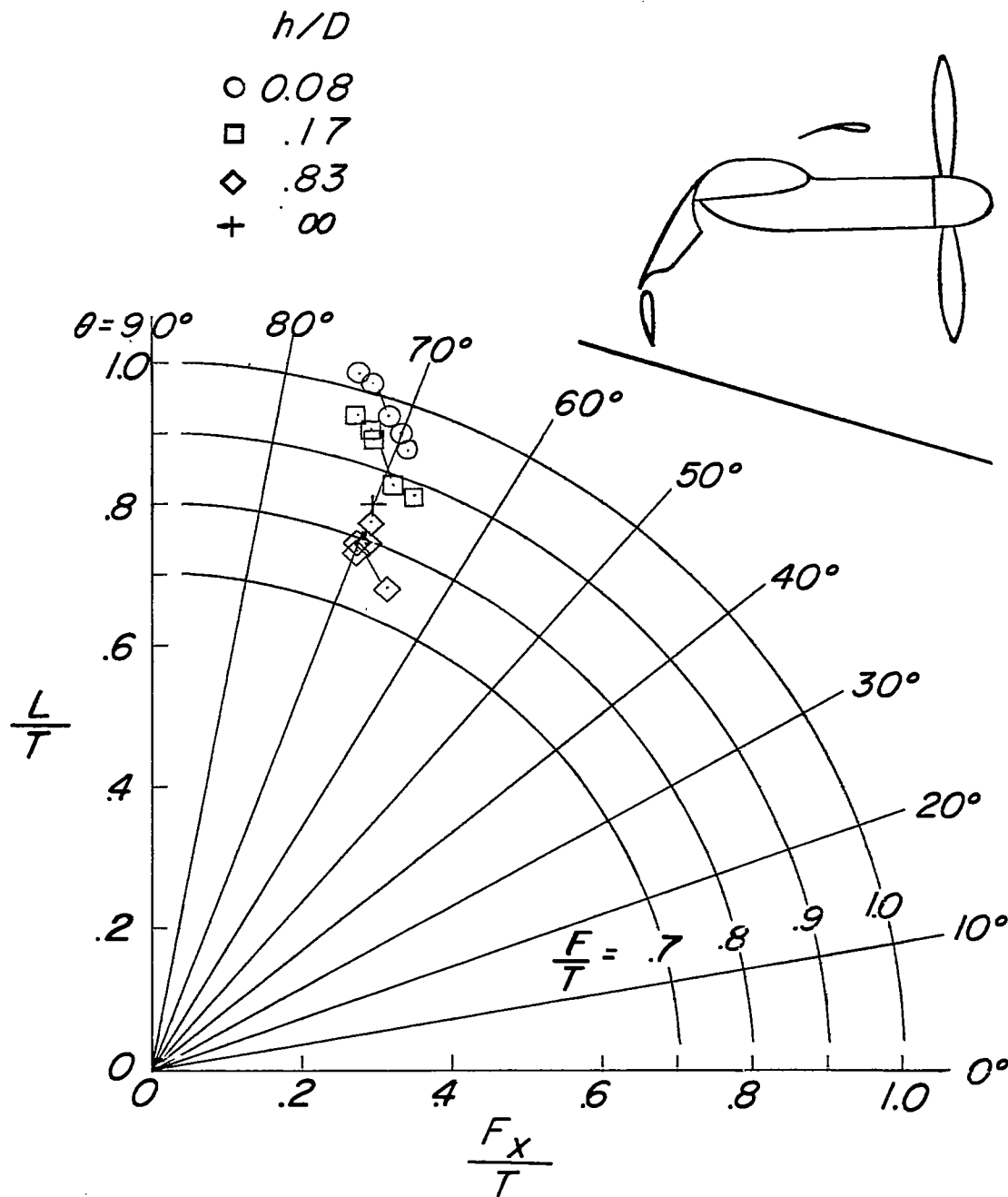


(b) Pitching moment.



(c) Ratio of resultant force to thrust.

Figure 15.- Effect of attitude with respect to ground. End plate on; slat on; $\delta_B = 10^\circ$; $\delta_{f,50} = 50^\circ$; $\delta_{f,30} = 40^\circ$.



(d) Summary of turning effectiveness.

Figure 15.- Concluded.

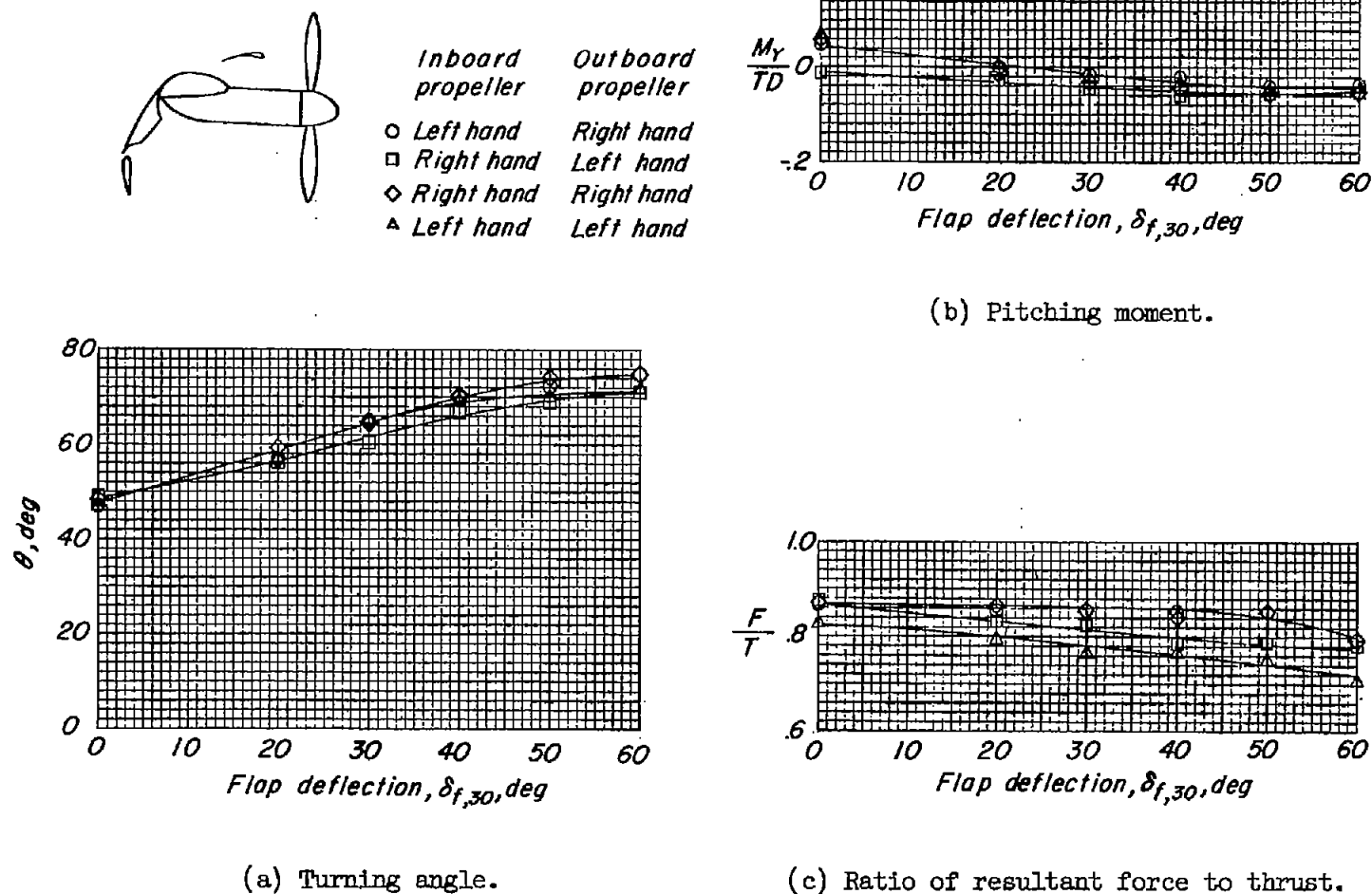
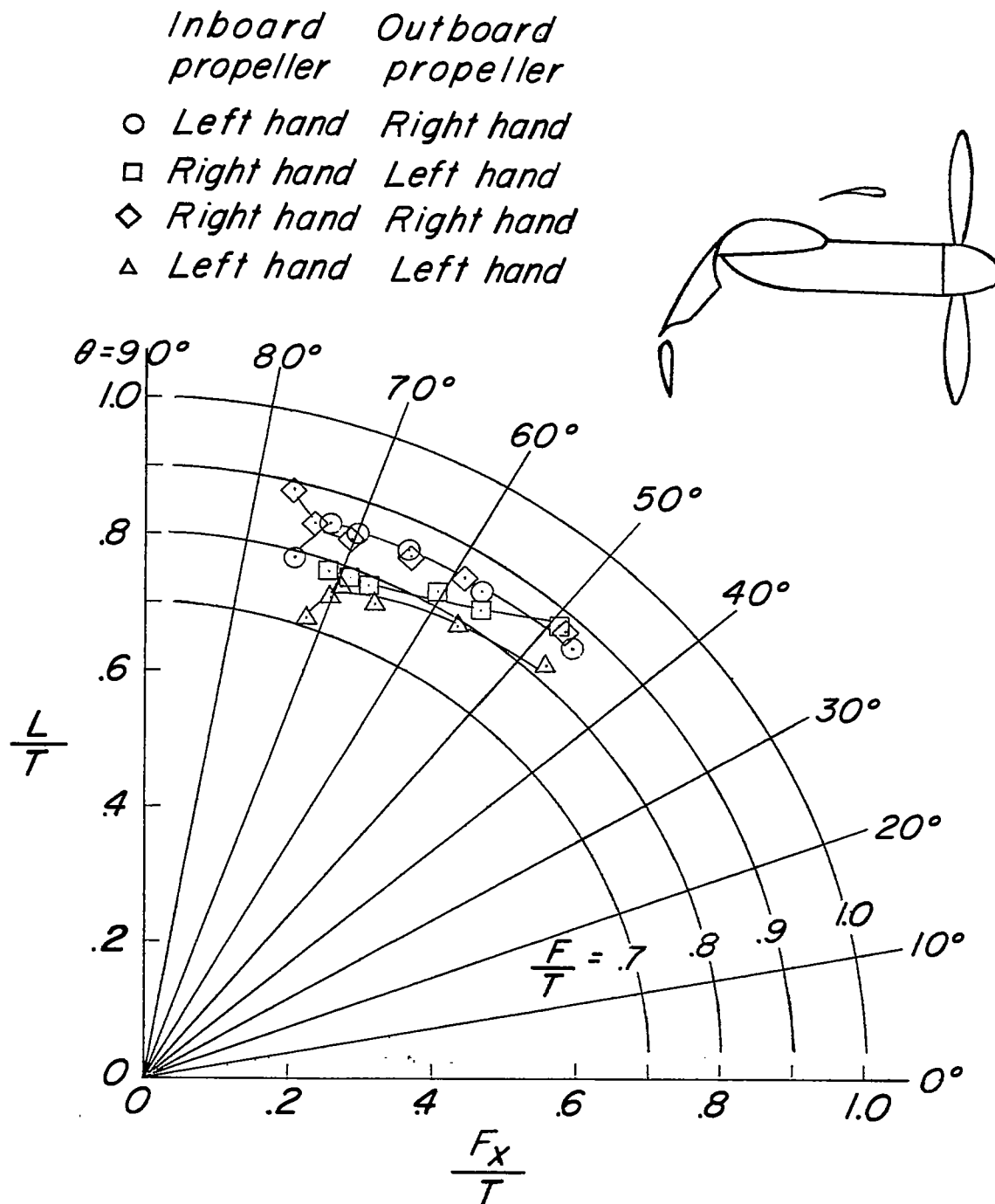


Figure 16.- Effect of mode of propeller rotation. End plate on; slat on; $\delta_s = 10^\circ$; $\delta_{f,50} = 50^\circ$; $h/D = \infty$.



(d) Summary of turning effectiveness.

Figure 16.- Concluded.

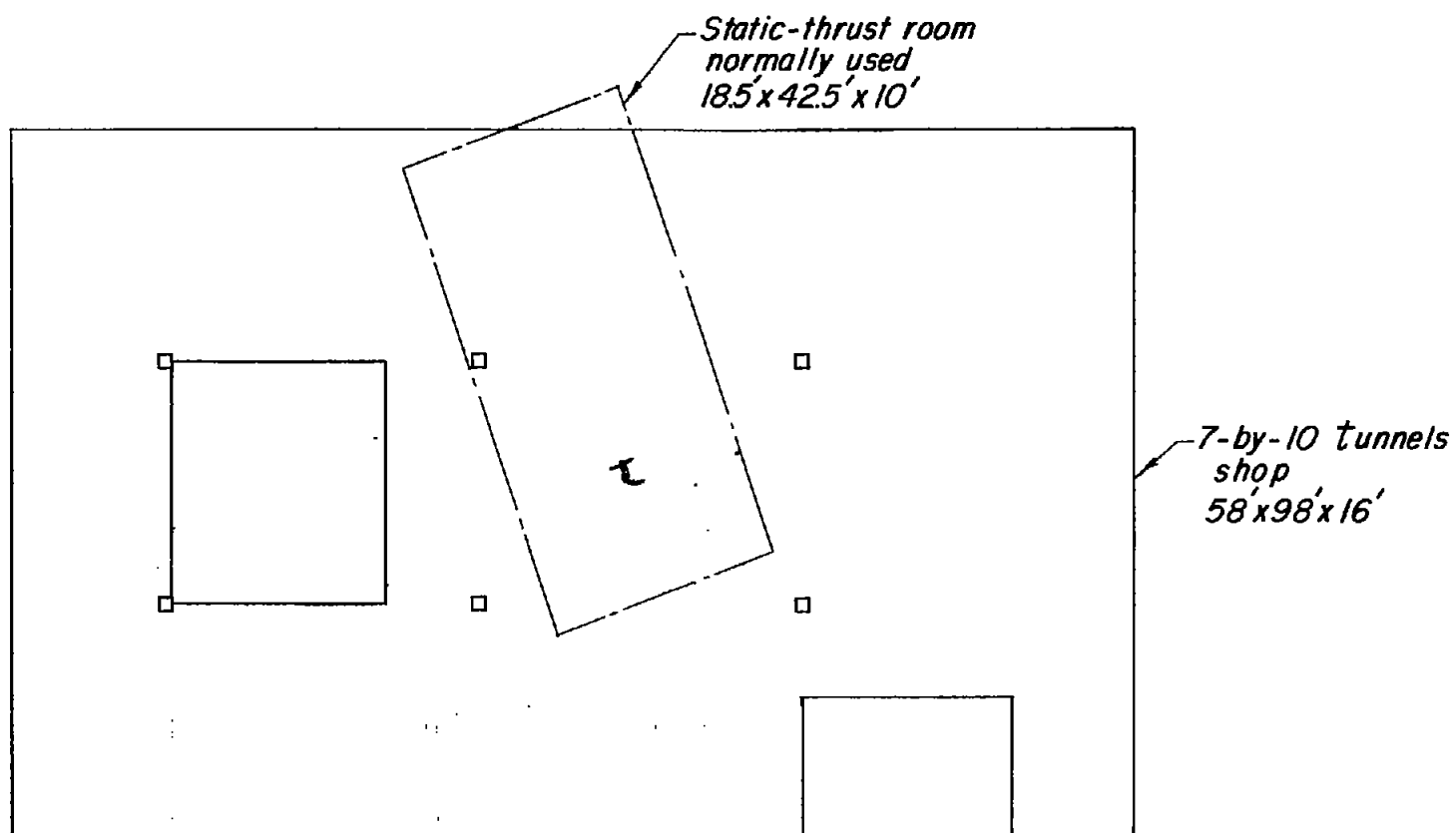


Figure 17.- Comparative size of the static-thrust facilities used.

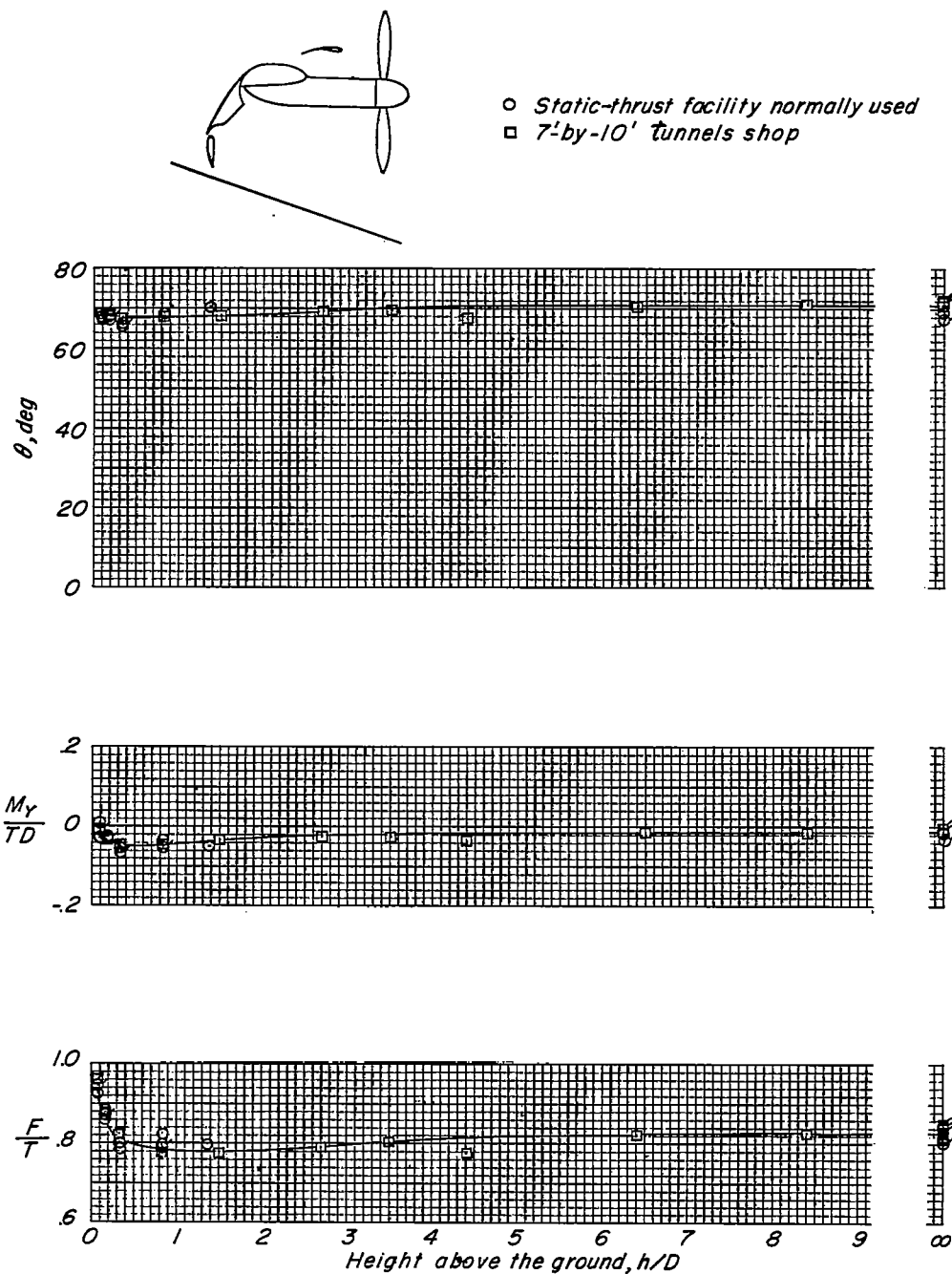


Figure 18.- Effect of test-facility size. End plate on; slat on; $\delta_s = 10^\circ$; $\delta_{f,50} = 50^\circ$; $\delta_{f,30} = 40^\circ$. (Flagged symbols are check points.)